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Contents

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8353-01, Session 1

A high-resolution SWIR camera via compressed sensing

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Images from a novel short wave infrared (SWIR, 900 nm to 1.7 μm) camera system are presented. Custom electronics and software are combined with a digital micromirror device (DMD) and a single element sensor, each of the later being commercial off the shelf devices, to create a lower cost imaging system than is otherwise available in this wavelength regime. A compressive sensing (CS) encoding schema is applied to the DMD to modulate the light that has entered the camera. This modulated light is directed to a single element sensor and an ensemble of measurements is collected. With the data ensemble and knowledge of the CS encoding schema, images are computationally reconstructed. The hardware and software combination makes it possible to create images with the resolution of the DMD while employing a substantially lower cost sensor subsystem than would otherwise be required by the use of traditional focal plane arrays (FPAs). The camera's architecture also enables adaptive functionality in the camera without additional hardware. We present results from solar exclusion experiments where bright pixels, that would otherwise reduce dynamic range in the images, are automatically removed.

8353-02, Session 1

Shortwave infrared camera with extended spectral sensitivity

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The SWIR spectral range has certain advantages for the observation during day under fog and haze weather conditions. Due to the longer wavelength compared to the visible spectrum the range performances in the SWIR is here considerably extended. In addition cooled SWIR focal plane arrays reach in the mean time sensitivities to be useable for night viewing under twilight or moon light conditions and potentially replacing thermal imagers and image intensifying tubes in some night viewing scenarios.

The presented SWIR camera system combines the color imaging in the visible spectrum with the imaging in SWIR spectrum. The 20x zoom optics is fully corrected between 440 nm and 1700nm. A dichroic beam splitter projects the visible spectrum on a color chip with HDTV resolution and the SWIR spectrum on a 640x512 InGaAs focal plane array. The open architecture of the camera system allows the use of different SWIR sensors and CMOS sensors. An universal designed interface electronic operates the used cameras and provides standard video outputs and compressed video streams on a ethernet interface. The camera system is designed to be integrated in various stabilized platforms. The camera concept is described and the comparison with pure SWIR or combined SWIR / MWIR dual band cameras are discussed from an application and system point of view.

8353-03, Session 1

SCD's cooled and uncooled photo detectors for NIR SWIR (Igor Szafranek Memorial presentation)

A. Fraenkel, D. Aronov, Y. Beny, L. Bikov, Z. Calahorra, T. Fishman, A. Giladi, E. Ilan, P. Klipstein, L. Langof, I. Lukomsky, U. Mizrahi, A. Tuito, M. Yassen, A. Zemel, SCD Semiconductor Devices (Israel)

Short wavelength Infra Red (SWIR) imaging has gained considerable interest in recent years. The main applications among others are: active imaging and LADAR, enhanced vision systems, low light level imaging and security surveillance systems.

In this paper we will describe SCD's recent efforts in this spectral region, addressing several platforms:

1. Extension of the mature InSb MWIR product line operating at 80K (cut-off wavelength of 5.4μm).

2. Extension of our new XBnn InAsSb "bariode" technology operating at 150K (cut-off of 4.1μm).

3. Development of InGaAs detectors for room temperature operation (cut-off of 1.7μm)

4. Development of a SNIR ROIC with a low noise imaging mode and unique laser-pulse detection modes.

In the first section we will present our latest achievements for the SWIR region in detail. Specifically, we will demonstrate our VGA, 15μm pitch, InGaAs arrays with dark current densities below 1.5 nA/cm2 at 280K, and high quantum efficiencies. In the second part, preliminary results for the NIR-VIS region are presented where advanced substrate removal techniques are implemented on flip-chip hybridized focal plane arrays.

8353-04, Session 1

Flexible wide dynamic range VGA ROIC for InGaAs SWIR imaging

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We present in this paper a flexible Wide Dynamic Range VGA ROIC for InGaAs SWIR imaging application. This ROIC incorporates not only the unique Solar Cell mode pixel design developed by NIT but also SF based linear function mode. The Solar cell mode pixel design can cover an instantaneous dynamic range of more than 140dB in a single frame without off-chip digital NUC, while the SF mode can operation sensor in a conventional SF linear mode with off-chip KTC noise cancellation possibility. This ROIC has been designed and fabricated with a standard 0.18um 1P3M process, compatible to 15um pitch InGaAs PDA. It can be operated at 100 Hz under full VGA resolution. The overall performance of this ROIC coupled to 35Lab extended visible InGaAs PDA will be presented at the conference.

8353-05, Session 1

High-performance 640 x 512 pixel hybrid InGaAs image sensor for night vision

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Hybrid InGaAs focal plane arrays are very interesting for night vision because they can benefit from the nightglow in the Short Wave Infrared band. Through a collaboration between III-5 Lab and CEA-Leti, a 640x512 InGaAs image sensor with 15μm pixel pitch has been developed. The readout IC (ROIC) design in a standard CMOS 0.18μm technology is presented. The pixel circuit is based on a capacitive transimpedance amplifier (CTIA) stage and offers a selectable gain. The input stage is optimized to deliver low noise performance at low light levels in the high gain mode. In this mode, the charge-to-voltage conversion factor is around 17.5μV/electron. The exposure time can be

maximized up to the frame period thanks to a rolling shutter approach. The frame rate can be up to 120fps or 60fps if the Correlated Double Sampling (CDS) capability of the circuit is enabled. The first results show a dark noise of 90 electrons for a full-well capacity above 105e3 electrons. They are obtained at room temperature with a reverse photodiode bias voltage of 100mV, the maximum exposure time (16ms at 60fps) and CDS. To our best knowledge, this set of results establishes state-of-the-art performance for this kind of detector.

8353-06, Session 1

InGaAs focal plane array developments at III-V Lab.

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SWIR detection band benefits from natural (sun, night glow, thermal radiation) or artificial (eye safe lasers) photons sources combined to low atmospheric absorption and specific contrasts compared to visible wavelengths. It gives the opportunity to address a large spectrum of applications such as defense and security (night vision, active imaging), space (earth observation), transport (road safety) or industry (process control).

InGaAs material appears as a good candidate to satisfy SWIR detection needs. The lattice matching with InP constitutes a double advantage to this material: attractive production capacity and uncooled operation thanks to low dark current level induced by high quality material.

For few years, III-VLab has been studying InGaAs imagery, gathering expertise in InGaAs material growth and imaging technology respectively from Alcatel-Lucent and Thales, its two mother companies. This work has lead to put on the market a 320x256 InGaAs module, exhibiting high performances in terms of dark current, uniformity and quantum efficiency.

In this paper, we present the last developments achieved in our laboratory, mainly focused on increasing the pixel number to VGA format associated to pixel pitch decrease (15µm) and broadening detection spectrum toward visible wavelengths. Depending on targeted applications, different Read Out Integrated Circuits (ROIC) have been used. Low noise ROIC have been developed by CEA LETI to fit the requirements of low light level imaging whereas logarithmic ROIC designed by NIT allows high dynamic imaging adapted for automotive night vision and road safety.

8353-07, Session 1

Low dark current small pixel large format InGaAs 2D photodetector array development at Teledyne Judson Technologies

H. H. Yuan, J. Kimchi, L. C. Kilmer, Teledyne Judson Technologies (United States)

Teledyne Judson Technologies (TJT) has been developing technology for small pixel, large format, low dark current, and low capacitance NIR/SWIR InGaAs detector arrays to produce 2Kx2K format arrays that can be operated at or near room temperature. Steady progress has been made in reducing the pixel size from 20µm to 10µm while continuing to reduce the dark current density for all pixel sizes. Furthermore, TJT is now developing technology for sub-10µm pixel arrays in response to requirements for a variety of low light level (LLL) imaging applications. In this paper, we will review test data that demonstrates lower dark current density for 10-20µm pixel arrays. In addition, we will present preliminary results on the successful fabrication of test arrays with pixels as small as 5µm. A variety of test array types, including 5µm, 6µm, 8µm, 10µm, 12µm, 15µm, and 20µm pixel sizes, were designed and fabricated on the same wafer, which also contains large format arrays of either 1280x1024 or 640x512. Comprehensive characterization of dark current dependence on reverse bias, operating temperature, and pixel size was performed using an advanced cold probe test station. The test data from test array structures confirm that pixels within an array are very well isolated from each other even for the 5µm pixel size. The probe tests show that we have achieved the average dark current density of 2.2nA/cm2 for 10µm pixels, 2.54nA/cm2 for 12µm pixels, 2.05nA/cm2 for 15µm pixels, and 2.04nA/cm2 for 20µm pixels at 23ºC and -100mV bias. For the sub-10µm pixel arrays, preliminary probe test data shows very promising performance, achieving the average dark current density of 28.6nA/cm2 for 5µm pixels, 25.2nA/cm2 for 6µm pixels, and 20.2nA/cm2 for 8µm pixels at 23ºC and -100mV bias. The dark current performance achieved from these sub-10µm pixel arrays already corresponds to a fairly low detector dark noise level at near room temperatures, close to meeting the requirements of many LLL imaging applications. In addition, these arrays are made from wafer structures designed for substrate removal, and hence the detector photoresponse can be extended to the UV-visible wavelength range with high quantum efficiency as was demonstrated in our previous work.

In addition, a lot of effort has been made to control or reduce the detector pixel capacitance which can become another source of detector noise. Extensive capacitance measurement was performed using the same probe station on various pixel sizes. The capacitance dependences on reverse bias and pixel size are presented and analyzed. Our test data shows that pixel capacitance of <10fF can be achieved at reverse bias for 10-15µm pixels. TJT now offers four different types of InGaAs 2D arrays/FPAs that are tailored to different customer requirements for dark current, capacitance, spectral response, and bias range.

8353-08, Session 1

Large-format InGaAs focal plane arrays for SWIR imaging

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FLIR will present their latest developments in large InGaAs focal plane arrays, which are used for low light level imaging in the short wavelength infrared (SWIR) regime. Aerius will present imaging from their latest small pitch (15 um) focal plane arrays in VGA and High Definition (HD) formats. FLIR will present characterization of the FPA including dark current measurements as well as the use of correlated double sampling to reduce read noise. FLIR will show daytime and nighttime imagery as well as data at high operating temperatures. The FPAs are characterized over temperature and this data will be presented. In addition, FLIR will show speckle-free illumination using their VCSEL products.

FLIR specializes in low dark current, high operability large InGaAs detector arrays. FLIR will show data from their Tau SWIR cameras utilizing both a 640x512, 25 um format and a 640x512, 15 um formats. Dark current data showing FPA performance lower than 0.5 nA/cm2 at 7°C will be shown. Characterization of the arrays with pulsed and cw illumination will be presented. With sub-nanosecond pulse lengths, the sensor non-linearity increases.

8353-09, Session 1

A low-power, TEC-less, 1280 x 1024, compact SWIR camera with temperature-dependent, non-uniformity corrections

J. Nazemi, M. Delamere, J. Battaglia, C. Martin, Goodrich ISR Systems (United States)

Significant research and development efforts are currently underway to produce robust Short Wave Infrared (SWIR) camera systems with very low power consumption. A substantial improvement in power can be achieved through the elimination of thermoelectric cooling (TEC) of the FPA. However, removing the TEC from the system introduces temperature as a major response parameter, effectively requiring more complex temperature dependent non-uniformity image correction algorithms. Since we last reported on these efforts, we have made significant technological advances through optimization of the hardware infrastructure and computational methods, leading to our development of low power compact TEC-less 1280x1024 and 640x512 SWIR cameras capable of real time image correction from -50C to 70C.

The camera under test was mounted inside of an environmental chamber and aligned such that a wide field homogenous light source was incident upon the FPA. Images at varying exposure times and illumination levels were acquired from -50C to 70C with a 10C step, yielding a dataset of FPA response characteristics from which two parameter non-uniformity corrections were calculated. The corrections were converted into fixed-point for use with the digital architecture of the camera. Several bit-depths were examined to find the smallest bit-depth allowable before the non-uniformity corrections produced unacceptable imagery.

Excellent non-uniformity image correction results were obtained with bit depths less than 96 bits per pixel. Preliminary studies suggest that 64 bps or less may be acceptable.

8353-10, Session 1

Ultralow flux SWIR detection issues using HgCdTe planar p-on-n photodiode arrays

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In this communication, we report first results carried out at CEA and Sofradir to build ultra low dark current FPA in the SWIR for space applications. Those FPAs are dedicated to very low flux detection in the 2µm wavelength range. In this purpose, Sofradir has designed a SFD ROIC, 384x288, 15µm pitch. This ROIC has been hybridized on different HgCdTe diode configurations processed at CEA-LETI and low flux characterisations have been carried out at CEA-SAP at low temperature (from 60 to 160K). Two different photodiode configurations have been tested. First, p/n As implanted diodes on In doped MBE material has been examined. A second configuration has also been explored, composed of n/p ion implanted diodes processed on vacancy doped LPE grown material (LETI standard technology). Hence both the technology (n/p vs p/n) and the metallurgical nature of the absorbing layer are compared in terms of dark current. Dark current measurements are discussed in comparison with previous results from the literature. State of the art dark currents are recorded for temperatures higher than 120K. Measurements show that if p/n diodes are superior to n/p diodes in terms of dark current in the diffusion regime at high temperature, it seems that p/n diode switch to a generation-recombination regime at a temperature far higher than n/p diodes. As a consequence, at low temperatures (below 180K) n/p diodes are on the same range of dark currents. At temperatures lower than 100K, the decrease in dark current saturates for both technologies. Nevertheless, in this regime, currents as low as 0.06e/s/pixel are reported.

8353-11, Session 2

Multispectral imaging with Type II superlattice detectors

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Infrared (IR) focal plane arrays with multispectral detector elements promise significant advantages for airborne threat warning, surveillance, and targeting applications. At present, the use of type II superlattice (T2SL) structures based on the 6.1Å-family materials (InAs, GaSb, and AlSb) for developing IR detectors has become an area of interest within the IR detector community. The ability to vary the bandgap in the IR range, suppression of Auger processes, prospective reduction of Shockley-Read-Hall centers by improved material growth capabilities, and the material stability are a few reasons for the predicted dominance of the T2SL detectors over presently leading HgCdTe and quantum well technologies. The focus of the work reported here is on the development of T2SL based dual-band IR detectors and their applicability for multispectral imaging. A new npBpn detector designed for the detection of IR in the 3-5 and 8-12 µm atmospheric windows is presented, comparing its advantages over other T2SL based approaches. One of the key challenges of the T2SL dual-band detectors is the spectral crosstalk between the two bands. The properties of the state-of-the-art T2SLs (i.e., absorption coefficient and minority carrier lifetime and mobility) and the present growth limitations that impact spectral crosstalk are discussed.

8353-13, Session 2

Space-based hyperspectral technologies for the thermal infrared

P. D. LeVan, Air Force Research Lab. (United States)

Various approaches now exist for obtaining spectral imagery over a broad range of infrared wavelengths. One involves use of a single grating element in two grating orders with dualband focal plane array (FPA) technology -- an approach offering high efficiency over both the MWIR & LWIR, and obviating the need for separate focal plane arrays, dispersing elements, and optical beamsplitters. Another approach achieves similar results by employing an FPA responding over a broad range of wavelengths with an innovative grating designed for high efficiency beyond the single octave limits of traditional gratings. Significant advantages result in either case for space-based hyperspectral imagers, for which a reduction in cryo-cooled mass translates into prodigious savings in overall mass, cryo-cooling requirements, and waste heat removal. Longer term approaches would realize infrared "hyperspectral pixels" in 2-D imaging focal plane arrays. In this case, each pixel would detect different wavelengths of radiation at different depths, and these "spectral photocurrents" would be transported to read-out circuitry through a vertical grid of electrical contacts. Although not yet realized in practice, the conceptual basis for accomplishing this with the widely-available HgCdTe detector material has been demonstrated.

Because space-based thermal HSI is characterized by coarser ground resolution as a result of aperture diameter limitations and diffraction considerations, resulting sub-pixel event detections are complementary with higher resolution panchromatic imagery. Overlapping fields-of-view could be used on the dayside of the earth for simultaneous correlation of spectral signatures with high resolution imagery; on the night-side, data collects are limited to the thermal hyperspectral images with no high resolution visible.

8353-14, Session 2

Hybrid dual-color MWIR detector for airborne missile warning systems

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Dual-color imaging in the Mid-Wave Infrared (MWIR) is required in some airborne Missile Warning Systems (MWS), where enhanced performance is achieved by comparing the signal in the two spectral bands. Furthermore, such systems demand high frame rate, spatial resolution, and spectral resolution, while at the same time call for simultaneous collection and readout of the two color images. Monolithic dual-color Focal Plane Arrays (FPAs) lack at least some of these requirements. In this work we introduce a new hybrid dual-color detector based on two 480×384/20um digital InSb FPAs, assembled in a single Dewar, where the high degree of spatial registration between the two color channels enables a solution that achieves the above requirements. Each FPA has its own cold shield and spectral filter, and the signal is snapshot integrated and read out in parallel to obtain complete dual-color simultaneity. The sensor imaging optics is integrated inside the Dewar

for both channels in order to reduce the overall system size and weight, and improve its performance at the extreme environmental conditions imposed by this application. In this case the hybrid dual-color Integrated Detector-Cooler Assembly (IDCA) is designed for a very wide field of view (~140 degrees), suited for the specific airborne MWS system. We present the standalone electro-optical results of both the red and the blue channels, together with the negligible spectral cross-talk and the high spatial registration between them.

8353-15, Session 2

Detection in urban scenario using combined airborne imaging sensors

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The EDA project on “Detection in Urban scenario using Combined Airborne imaging Sensors” (DUCAS) is in progress. The aim of the project is to investigating the potential benefit of combined high spatial and spectral resolution airborne imagery for several defence applications in the urban areas. The project is taking advantage of the combined resources from 7 contributing states within the EDA framework. An extensive field trial has been carried out at Zeebrugge at the Belgian coast during June 2011. The Belgian armed forces contributed with platforms, weapons, personal (soldiers) and logistics for the trial. Ground truth measurements with respect to geometrical characteristics, optical material properties and weather conditions were obtained.

For hyperspectral imagery sensors, the signal processing includes atmospheric characterisation and correction, spectral properties retrievals, feature extraction based on physics and phenomenology for the purpose of detection and classification algorithms development. High resolution sensor data are used for classification and identification. Preliminary observations will be presented.

8353-16, Session 2

IR-CENTRIC®: a force multiplier for fixed and rotary wing aircraft

T. Rozen, S. Nadav, M. Danino, Elbit Systems EW & SIGINT - ELISRA Ltd. (Israel)

The constant evolution of asymmetric threats to military and commercial aviation requires a revolutionary approach - a revolution in technology, a revolution in functionality, and above all, a revolution in state of mind.

Today, when the focus is on uncompromising excellence in mission planning, safety, and success, a unique approach must be considered. This new approach must challenge existing ad-hoc, single-function, and single-usage systems. It now calls for multi-function, multi-usage, all-in-one solutions, which in effect, constitute a force-multiplier.

The paper will highlight recent developments in IR technology and use, making the point that IR technology should be considered a necessity in current and future safety and survivability developments. The presentation will address “all-in-one” solutions which cover: missile and hostile-fire detection and warning, optimal and accurate activation of countermeasures (protection from first shot), situational awareness, collision alert, mission support, etc.

8353-17, Session 2

Half TV format MWIR sensor incorporating proximity electronics

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The sensor consists of an integrated detector-cooler assembly and custom proximity electronics mounted in a lightweight, ruggedized housing. Based on the half-TV format Osprey-S FPA, it implements recent developments in SELEX Galileo’s array hybridization technique to improve array survivability. Recent tests have shown that performance is not significantly degraded after more than 5000 cooldown cycles. The FPA is optimized for high temperature operation and very low levels of defective pixels (<0.003%) have been achieved at 110K. The proximity electronics are SELEX Galileo’s own design. They provide all the necessary supplies and signals for detector operation and digitize the detector output into 14-bit digital video. The sensor has been developed to offer a very lightweight, rugged camera core particularly suited to airborne applications.

8353-18, Session 2

Comparison of the strapdown and gimballed seekers

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In order to orient aerial vehicles such as unmanned aerial vehicles and guided munitions toward intended target points, it often becomes vital to acquire the correct information about the states of the targets during the flight of the vehicles. One of the most widely-used ways to achieve this task is the utilization of seekers. Physically, the measurement capability of seekers is restricted due to some physical, optical, and electronic limitations such as limited field-of-view (FOV), atmospheric transmittance, and noise effects. Regarding these characteristics, basically two types of seekers are employed in the relevant applications: strapdown or body-fixed seekers and gimbaled seekers. The strapdown seekers are directly mounted on the considered vehicle body. Therefore, their measurements become relative to the body fixed reference frame of the missile. For relieving the FOV limitations of the strapdown seekers, the gimbaled seekers are preferred in some of the implementations. In this scheme, the seeker is mounted on a platform supported by two orthogonal gimbals and stabilized by means of rate gyro feedbacks. This way, the FOV range of the seeker is increased considerably. Also, the LOS angle and the LOS angular rate can be measured directly independently of the missile motion. This study deals with the comparison of these two kinds of seekers according to certain criteria involving mounting properties, FOV, angle and rate measurements, guidance method utilization, measurement methods, major sources of measurement errors, and cost. A general evaluation is submitted at the end of the work.

8353-19, Session 2

Anti-dazzling protection for Air Force pilots

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Dazzling and damage to helicopters and aircrafts pilots eye and/or goggles, from laser pointer and other lasers, is well known problem nowadays. One proposed solution is to use a notch filter to allow only a narrow band of wavelength. However, these types of filters block power at a specific wavelength regardless of the power level and the available wavelength-agile lasers make this strategy useless. The major drawbacks of this solution are that the color impression may be affected and that the protection is limited to specific wavelengths only, whereas the threats can exist in any other laser wavelengths. Smart protection is needed, that is transparent for low input intensities and limit or block the high input intensities, and is effective over a wide band of wavelengths.

KiloLambda developed Optical Power Control (OPC) devices that reduce laser power threat to a safe level for various optical systems. KiloLambda's Wideband Protection Filter (WPF) product is a wideband, angle of impingement independent, solid-state filter that protects sensors, cameras and the human eye from over power laser threats. We propose, based on our proven technologies, a wideband dazzling protection goggles for air-force pilot applications.

8353-141, Session 2

Radiation tolerance of a dual-band IR detector based on a pBp architecture

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Infrared (IR) detectors operated in the space environment are required to have to high performance while being subjected to a variety of radiation effects. Sources of radiation in space include the trapped particles in the Van Allen belts and transient events such as solar events and galactic cosmic rays. Mercury cadmium telluride (MCT)-based IR detectors are often used in space applications because they have high performance and are generally relatively tolerant of the space environment when passivated with CdTe; often, the readout-integrated circuit is far more susceptible to radiation effects than the detector materials themselves. However, inherent manufacturing issues with the growth of MCT have led to interest in alternative detector technologies including type-II Strained Layer superlattice (SLS) infrared detectors with unipolar barriers. Much less is known about the radiation tolerance properties of these SLS-based detectors compared to MCT. Here, the effects of gamma-ray radiation on a dual-band InAs/GaSb SLS detector in the pBp architecture are considered. Gamma-rays act as a convenient ionization source, via the Compton scattering mechanism, that produce similar effects as high energy electrons in space. The SLS detectors tested here utilize a pBp architecture, which takes advantage of the higher mobility electrons as the minority photocarrier. These detectors are also dual-band, with cutoff wavelengths of 5 and 9 µm allowing for mid-wave (MWIR) and long-wave (LWIR) infrared detection. The radiation effects on the detector are characterized by dark current, quantum efficiency, and lateral diffusion length measurements, all as a function of total ionizing dose (TID).

8353-20, Session 3

Stereoscopic uncooled thermal imaging with autostereoscopic 3D-flat screen display in military driving enhancement systems

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Thermal cameras are widely used in driver vision enhancement systems. However, in pathless terrain, driving becomes challenging without having a stereoscopic perception. Stereoscopic imaging is a well known technique already for a very long time with understood physical and physiological parameters. Recently, a commercial hype has been observed, specially in display techniques. The commercial market is already flooded with systems based on goggle-aided 3D-viewing techniques but the use is limited for military applications because goggles are not accepted by the military user for different reasons.

The proposed uncooled thermal imaging stereoscopic camera with a geometrical resolution of 640x480 pixel perfectly fits to the autostereoscopic 10.6 inch display with a 1280x768 pixels. The display is not timely and spatial limited because of the inherent low resolution of the uncooled camera. An eye tracker detects the position of the observer's eyes and computes the pixel positions for the left and the right eye. The pixels of the flat panel are located directly behind a slanted screen raster and the computed thermal images are projected into the left and the right eye of the observer. This allows a stereoscopic perception of the thermal image without any viewing aid like a 3 D goggle. The complete system including camera and display is ruggedized.

The two thermal imagers are bore sighted and synchronised for optimal stereo viewing of a dynamic thermal scene. The thermal and geometrical resolution is good enough to extract signatures for the stereoscopic view. The paper discusses the interface and performance requirements for the thermal imager as well as for the display.

8353-21, Session 3

Infrared stereo camera for human machine interface

R. Edmondson, D. B. Chenault, J. P. Vaden, Polaris Sensor Technologies, Inc. (United States)

Improved situational awareness results not only from improved performance of imaging hardware, but also when the operator and human factors are considered. Situational awareness for IR imaging systems frequently depends on the contrast available. A significant improvement in effective contrast for the operator can result when depth perception is added to the display of IR scenes. Depth perception through flat panel 3D displays are now possible due to the number of 3D displays entering the consumer market. Such displays require appropriate and human friendly stereo IR video input in order to be effective in the dynamic military environment. We report on a stereo IR camera that has been developed for integration on to an unmanned ground vehicle (UGV). The camera has auto-convergence capability that significantly reduces ill effects due to image doubling, minimizes focus-convergence mismatch, and eliminates the need for the operator to manually adjust camera properties. Discussion of the size, weight, and power requirements as well as integration onto the robot platform will be given along with description of the stand alone operation.

8353-23, Session 3

A compact deployable mid-wave infrared imaging system for wide-area persistence surveillance in maritime environments

K. P. Judd, U.S. Naval Research Lab. (United States); C. Colbert, R. Smith, Smart Logic, Inc. (United States); K. M. Vilardebo, V Systems, Inc. (United States); J. R. Waterman, U.S. Naval Research Lab. (United States); G. J. Petty, J. Kilzer, Naval Surface Warfare Ctr. Crane Div. (United States)

The development, integration and testing of a compact system for wide-area persistence surveillance in dedicated maritime environments is presented. The system is based on a large-format, 2560 x 512 pixel focal plane array, high dynamic range (16 bit), mid-wave infrared (MWIR) imager operating at 30 Hz that is equipped with a 90° horizontal field-of-view (HFOV) lens. The digitized image data is fed to a standard commercial-off-the-shelf (COTS) workstation equipped with a graphical processing unit (GPU) that is used to perform image de-warping, non-uniformity corrections and runs the algorithms for real-time object detection and tracking (NRL Harbor Tracking Software-NRLHaTS). Data is presented from several field experiments that illustrate the capabilities of the integrated system.

8353-24, Session 3

OTHELLO: a novel SWIR dual-band detection system and its applications

G. A. Tidhar, O. Aphek, Israel Aerospace Industries Ltd., Elta Group (Israel)

Following a several years course of development, OTHELLO is the latest generation of SWIR based optical detection and warning systems.

We describe OTHELLO's novel dual band high rate imaging and on-sensor board signal processing architecture which allows for integration with various land, naval and airborne systems, with specifically enhanced capabilities in dynamic and high-speed movement scenarios.

OTHELLO's unique false alarm mitigation capabilities and integration with IAI radar detection systems are also described.

8353-25, Session 3

Quantification of nitromethane with complementary super clip apodization and an iterative spectral comparison routine

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The work presented here proposes a signal processing strategy for the quantification of a known substance without the acquisition of a background spectrum using a Fourier transform infrared (FT-IR) spectrometer. Complementary super clip apodization (CSCA) truncates the central burst and subtracts this result from the whole interferogram in the frequency domain to calculate the emission spectrum of the background light source. It will be discussed that the width of the time domain filter, or the number of points truncated from the maximum value of the central burst, is not only interferogram but also frequency dependent. The software written for this method uses spectral comparison algorithms conventionally employed in library search routines to iteratively adjust the filter width and compare it to a library file. In this fashion, an optimal spectrum can be calculated regardless of fluctuations in the power of the light source or in a sampling environment that is not static. The novelty of this work is the method in which the background spectrum is generated as well as the iterative comparison technique employed by the software for spectral optimization. A quantitative analysis study of gas-phase nitromethane compared the spectra calculated by the instrument software to the spectra calculated by the software discussed above. The primary region of interest was between 630-660 wavenumbers, and a secondary study was performed on the asymmetric nitro stretch between 1520-1640 wavenumbers. Both studies produced results that were at least comparable to the instrument output involving the acquisition of separate reference and sample spectra.

8353-26, Session 3

On designing a SWIR multiwavelength facial-based acquisition system

T. Bourlai, N. Narang, B. Cukic, L. A. Hornak, West Virginia Univ. (United States)

In harsh environmental conditions characterized by unfavorable lighting and pronounced shadows, human recognition based on Short-Wave Infrared (0.9-1.7 microns) images may be advantageous. SWIR imagery (i) is more tolerant to low levels of obscurants like fog and smoke; (ii) the external illumination source can be eye-safe and (ii) the external illumination source is invisible to the human eye making it suitable for surveillance applications. The key drawback of current SWIR-based acquisition systems is that they lack the capability of real-time simultaneous acquisition of multiple SWIR wavelengths. The contributions of our work are four-fold. First, we constructed a SWIR multi-wavelength acquisition system (MWAS) that can capture face images at 5 different wavelengths (1150-1250-1350-1450-1550 nm) in rapid succession using a 5-filter rotating filter wheel. Each filter has a band pass of 100 nm and all 5 images are acquired within 260 milliseconds. The acquisition system utilizes a reflective optical sensor to generate a timing signal corresponding to the filter wheel position that is used to trigger each camera image acquisition when the appropriate filter is in front of the camera. The timing signal from the reflective sensor transmits to a display panel to confirm the synchronization of the camera with the wheel. Second, we performed an empirical optimization on the adjustment of the exposure time of the camera and speed of the wheel when different light sources (fluorescent, tungsten, both) were used. This improved the quality of the images acquired. Third, a SWIR spectrometer was used to measure the response from the different light sources used and evaluated which one provides better images as a function of wavelength. Finally, the selection of good quality SWIR images was determined by using a number of image quality and distortion metrics (e.g., sharpness, universal quality index etc.).

8353-27, Session 4

Recent developments in type-II superlattice detectors at IRnova AB

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A mid wave infrared type-II superlattice focal plane array with 320x256 pixels, 30 µm pitch and 90 % fill factor was processed in house, using a conventional homojunction p-i-n photodiode architecture and the ISC9705 readout circuit. High-quality imaging up to 110 K is demonstrated with the substrate fully removed. The absorber is 2 µm thick, and no anti-reflection coating was used, so there is room for significant improvement of the quantum efficiency, which is in the 40 % range.

Studies of the dark current-vs.-temperature behavior indicate that the device is limited by Shockley-Read-Hall generation from the depletion region. The activation energy of this dark current component is 0.13 eV, suggestive of an unidentified recombination center positioned halfway into the 0.24 eV bandgap.

Furthermore, we report on detectors with 100 % cut-off at 13 µm. The dark current density at 60 K and -0.05V bias is 2x10-4 A/cm2. Quantum efficiency, NETD and BLIP temperature is also calculated.

Position-sensitive photocurrent measurements on mesa etched superlattice material were made at low temperatures using a focused laser spot. The lateral diffusion length of holes was extracted and will be reported.

8353-28, Session 4

Long-wavelength infrared superlattice detectors and FPA based on CBIRD design

A. Soibel, S. B. Rafol, J. Nguyen, A. Khoshakhlagh, L. Höglund, S. A. Keo, J. M. Mumolo, J. K. Liu, A. Liao, D. Z. Y. Ting, S. D. Gunapala, Jet Propulsion Lab. (United States)

The antimonide material system has a great potential for realization of high-performance infrared detectors. Superlattice (SL) detectors utilizing InAs/GaSb/AlSb layers can be designed to have cutoff wavelengths ranging from the short wave infrared (SWIR) to the very long wave infrared (VLWIR). These detectors offer an advantage of suppressed Auger recombination rates and low interband tunneling thus resulting in the improved detector performance due to suppression of dark currents. Furthermore, complex heterodiodes with improved performance can be realized in this material system by introduction of unipolar barriers, which blocks one carrier type without impeding the flow of the other.

In this work, we discuss our recent efforts on advancing of antimonide superlattice based infrared photodetectors. By optimizing design and growth condition we succeeded to reduce the operational bias of CBIRD single pixel detector to be less than 50mV without increase of dark current or degradation of quantum efficiency. The 10 um cutoff superlattice device detector, without anti-reflection coating or passivation, exhibits a responsivity of 2 A/W and a dark current density

of less than 1e-5 A/cm2 at 77K under 0.05 V bias. Using this material, Focal Plane Arrays were fabricated utilizing an effective dry etching, hybridization and thinning processes developed at JPL. The resulting 320x256 FPA has yielded noise equivalent differential temperature of 26 mK at operating temperature of 80 K, with 300 K background and cold-stop. These results advance state-of-the art of superlattice detectors and demonstrated advantages of CBIRD architecture for realization of FPA.

8353-32, Session 4

Development of type II superlattice detector for future space applications at JAXA

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Infrared sensor technology is a key technology to realize JAXA's future missions. In the infrared sensor to realize these missions, infrared detectors are the most important component which has a great influence on the system performance. In order to realize higher mission requirements, JAXA has decided to position the infrared detector technology as one of the strategic technologies and to promote the development of the infrared detectors. Type II superlattice (SL) detector is selected for this program. Type II SL is the only known IR material that has a theoretically predicted higher performance than HgCdTe.

In this paper, we report on the first results of the development of Type II SL detectors of mid-wave infrared region. The type II SL crystal was grown with solid-source MBE, using a Veeco Gen II system at National Institute of Information and Communications Technology (NICT). The detector structure is a pin photodiode with SL of 9 InAs monolayers (MLs) and 7 GaSb MLs. The evaluation of crystalline quality shows a strain between the GaSb buffer and SL is 0.04%. We also present results of optical evaluation of the detector. The cutoff wavelength is 5.5um at 30K. The responsivity is 0.5 A/W at 4.8um, which is correspond to the quantum efficiency of 13%.

8353-29, Session 5

Advanced imaging R&D at DARPA-MTO

N. K. Dhar, Defense Advanced Research Projects Agency (United States)

No abstract available

8353-30, Session 6

Performance enhancement of III-V superlattice infrared detectors by solving material and fabrication issues

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In the past few years we have witnessed rapid progress in the development of III-V superlattice infrared detectors and focal plane arrays. This is reflected by recent publications that show the dark current density of the best single-element large-area detectors is similar to that of the best HgCdTe detectors at long-wavelength infrared (LWIR), the performance of median noise-equivalent difference temperature (NEDT) of LWIR large format FPAs is sufficiently good for many applications in which HgCdTe FPAs are currently used, and very respectable two-color FPAs are being successful demonstrated. However, in order to further improve detector and FPA performance, better understanding is required on material issues and the impact of every processing step used in FPA fabrication. With limited funding, systematic experimental and modeling studies have been carried out to understand interdependencies of various physical parameters, such as dark current, quantum efficiency, minority carrier lifetime, detector structure, doping, and etching and passivation protocols. This talk presents an update on recent progress, as well as the material and process studies.

8353-31, Session 6

Recent advances in 2 colors FPAs based on T2SL; InAs/GaSb

M. Razeghi, Northwestern Univ. (United States)

Type-II InAs/GaSb superlattices is an excellent candidate for multi-band infrared detection thanks to its tunable and versatile band structure as well as its proven high detectivity performance. In this work, we review the progress to-date on the design of dual band detectors, which are largely based on previous work incorporating superlattice barriers in single color p-n junctions. Building upon this foundation, back-to-back dual-band photodiodes were realized in the LWIR/LWIR. In turn, we will also discuss the advancement made in developing focal plane arrays with excellent temperature sensitivities in both 320x256 and 640x512 formats operating at 81K.

8353-33, Session 6

Temperature-dependent absorption derivative on InAs/GaSb Type II superlattices

B. Klein, N. Gautam, S. A. Myers, S. Krishna, Ctr. for High Technology Materials, Univ. of New Mexico (United States)

We present an investigation of the quantum confined energy levels in a mid-wave infrared strained-layer superlattice photodetector by computing the first derivative of the absorption spectra, with respect to the wavelength, from 80K to 250K. Energy levels of both the fundamental transition and two other higher orders are identified for the superlattice. These results are compared to previously-reported theoretical calculations, which show that theory overestimates the bandgap energy by tens of meV over all of k-space. The temperature evolution of each of these bands was also characterized by means of the Varshni equation, and it is found that all bands react similarly to temperature changes. By substituting the Varshni equation into the intrinsic carrier equation, the product of effective masses was found for each transition. Assuming the curvature of the valence bands to be invariant from band to band, the curvature of electron bands relative to the valence bands was determined.

8353-34, Session 6

Electronic transport in InAs/GaSb type-II superlattices for infrared detector applications

G. A. Umana-Membreno, H. Kala, J. Antoszewski, L. Faraone, The Univ. of Western Australia (Australia); B. Klein, N. Gautam, M. Narayanan Kutty, E. Plis, S. Krishna, The Univ. of New Mexico (United States)

Infrared sensors are of great importance due to their multitude of applications in defense and security, medical diagnostics and scientific instrumentation, agriculture, environmental monitoring and mineral exploration. Recently, InAs/GaSb type-II strained layer superlattices (SLS) have attracted significant research efforts due to their promising properties for the detection of infrared radiation. While theoretically

InAs/GaSb SLS based infrared sensors should significantly outperform current state-of-the-art HgCdTe-based detectors, this potential has yet to be fully realized, thus prompting further research into the fundamental physics of InAs/GaSb superlattices. In this work, we report results of a study of electronic transport in a p-doped InAs/GaSb SLS with nominally 10µm cut-off for both the vertical and lateral directions (along and perpendicular to the SLS growth direction, respectively). Magnetic-field dependent characterization and mobility spectrum analysis has been employed to extract the transport parameters of all carrier species in the samples. In the vertical direction, corresponding to the typical array pixel configuration and thus of relevance to detector performance, two "bulk" SLS carriers assigned to majority hole and minority electron species have been identified with respective mobilities of 300cm2/Vs and 2,500 cm2/Vs at 80K; whereas in the lateral direction the extracted mobilities for SLS holes and electrons were 10,500cm2/Vs and 16,000cm2/Vs, respectively, also at 80K. The significant anisotropy in transport parameters needs to be taken into account in detector design and optimization.

8353-35, Session 6

1024 x 1024 LWIR SLS FPAs: status and characterization

M. Sundaram, A. Reisinger, R. Dennis, K. Patnaude, D. Burrows, J. Bundas, K. E. Beech, R. Faska, D. Manitakos, QmagiQ, LLC (United States)

An infrared sensor technology that has made quick progress in recent years is the photodiode based on Type-II InAs/(In)GaSb strained layer superlattices (SLS). We have developed Focal Plane Arrays (FPAs) with upto a million pixels, quantum efficiency exceeding 50%, and cutoff wavelength of ~ 10 microns. SLS offers the promise of the high quantum efficiency and operating temperature of longwave infrared (LWIR) mercury cadmium telluride (MCT) at the price point of midwave infrared (MWIR) indium antimonide (InSb). That promise is rapidly being fulfilled. This talk will review the current state-of-the-art of this sensor technology at this critical stage of its evolution.

8353-36, Session 6

Passivation of type II InAs/GaSb superlattice photodetectors with atomic layer deposited Al_2O_3

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Type-II super lattice (T2SL) InAs/GaSb photodetectors are received great interest in the development of midwave and long wave infrared detectors, due to their advantages like capability of band gap engineering, suppression of auger recombination, suppressing the interband tunneling. Type-II super lattice technology is a very promising alternative to MCT and QWIP in the focal plane array (FPA) applications where, low background current below 78 K is required. One of the challenges of T2SL system is the large number of surface states generated due to the abrupt termination of the crystal structure at the side walls. Dangling bonds, inversion layer and interfacial traps are also source of surface leakage currents. In order to overcome surface leakage currents of small sized photodetectors, various passivation methods proposed to solve the problem, such as ammonium sulfide passivation, deposition of silicondioxide layer or a polyimide layer, Overgrowth with wide bandgap material. Passivation suppress oxidation of the side walls and saturate dangling bonds to prevent surface states.

We propose Atomic layer deposited (ALD) Aluminum Oxide (Al2O3) passivation technique for type II InAs/GaSb superlattice midwave infrared (MWIR) single pixel photodetector. Al2O3 passivated and unpassivated diodes were compared for their electrical and optical performances. The dark current density was improved by one orders of magnitude for passivated diodes at 77 K. The zero bias responsivity and detectivity was equal to 1.33 A/W and 7.6 × 10 ^13 Jones, respectively at 4 µm and 77 K. Quantum efficiency (QE) was calculated as %41 for Al2O3 passivated single pixel photodetectors at 77 K.

8353-37, Session 6

Analysis surface oxides on narrow band III-V semiconductors toward surface-leakage-free IR photodetectors

Q. Wang, Acreo AB (Sweden); M. Göthelid, Kista Photonics Research Ctr. (Sweden); E. Göthelid, Uppsala Univ. (Sweden); S. Almqvist, A. Karim, Acreo AB (Sweden); O. Gustafsson, M. Hammar, Kista Photonics Research Ctr. (Sweden); J. Y. Andersson, Acreo AB (Sweden)

Narrow-band semiconductors GaSb (Eg= 0.7 eV), InAs (Eg=0.36 eV), and InSb (Eg=0.17 eV) are important building blocks for constructing novel quantum structures, such as type-II InSb based quantum dots and InAs/GaSb strained layer superlattice (SLS), to design and fabricate mid wavelength (MWIR) or long wavelength infrared (LWIR) photodetectors. However, these III-V narrow band semiconductors are known to possess a large number of surface states due to surface oxides and contaminations, dangling bonds, material or process induced defects that cause serious shunt current. Hence, an analysis and understanding of their surface chemical composition can provide valuable hints to optimizing device surface passivation techniques leading towards surface leakage free IR photodetectors.

We report on the investigation into Ga-, In-, Sb-, and As-oxides and other chemical species on the surface of untreated control, dry etched and thermally passivated GaSb, InAs and InSb samples by X-ray photoelectron spectroscopy (XPS). It is worth to note that the dry etching is a key step to form the mesas of the infrared detectors, which often could cause surface states on the mesa's sidewalls. The experimental results reveal presence of Sb-oxides on surfaces of the untreated and treated GaSb samples, but Ga-oxide was not pronounced. Both Sb- and In-oxides were observed on the surface of all InSb samples, and especially the dry etched sample had thicker oxide layers. For InAs samples, not only In- and As-oxides XPS signals were obtained, but also AsCl species were found from the dry etched sample. These results have been used to analyze the surface passivation mechanism of our fabricated IR detectors.

8353-38, Session 6

Unrelaxed InAsSb with novel absorption, carrier transport, and recombination properties for MWIR and LWIR photodetectors

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Carrier lifetime studies in narrow-gap InAs-GaSb strained layer superlattices (SLS) pointed at Ga-Sb antisite defects as a likely channel of carrier recombination. Ga-free materials such as InAsSb alloys or InAs-InSb SLS are expected to demonstrate different recombination properties. The hole transport in bulk materials is expected to improve compared to SLS. This work reports on properties of unrelaxed and unstrained InAs1-XSbX layers with a broad range of X grown by solid-source MBE. The InAsSb layers were lattice matched to the topmost section of Ga(Al)InSb compositionally graded metamorphic buffer layers grown on GaSb substrates. With a grading rate of near 0.5 % per µm, the topmost section of the buffer remained unrelaxed under a small residual strain in accordance with expectations. The results were confirmed by HRXRD reciprocal space mapping obtained near (004) and

(335) reflections to characterize tilt, strain and relaxation, and by TEM to examine the dislocation morphology. Bulk InAsSb layers with a thickness up to 1.5 μm were grown. The surface morphology was characterized by AFM. Minority carrier lifetimes up to 350 ns were measured in InAs0.8Sb0.2 layers at 77 K with the PL peak at 5.2 μm, a broad PL spectrum was observed at room temperature with a maximum near 6 μm. InAs0.56Sb0.44 layers showed comparable PL intensities at 150 K with a peak at 9.5 μm extending beyond 12 μm. The PL peak wavelengths for unrelaxed InAsSb were found to be considerably longer than reported previously for InAsSb alloys with various degrees of strain.

8353-39, Session 6

100mm GaSb substrate manufacturing for IRFPA epi growth

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Mega-pixel FPAs in both MWIR and LWIR spectral bands that are grown using SLS epi structures on GaSb substrates have recently demonstrated impressive performances at high operating temperatures. An essential component of SLS molecular beam epi growth initiation is the starting wafer flatness, smoothness and haze. Using a double side polishing process, 100mm GaSb substrate processing has resulted in consistent starting wafer flatness well below 5µm of warp and bow. The extreme temperatures of the substrate imposed during the epi growth require sufficient wafer strength to maintain a final device flatness. This paper examines the correlation of the tracked starting interferometry measurements to the warp, bow, and TTV measured after the MBE growth of a Sb- based type-II superlattice structure. Final substrate/epi Surfscan mapping (~1000/cm2 particles) and surface roughness (Rms 10µm of wafer warp from the epi process, but device fabrication would be viable. A clean substrate to epi transition with excellent surface crystallinity is suggested by the strong superlattice periodicity and low FWHM (~15 arcsec) of the XRD spectrum.

8353-40, Session 6

Large diameter ultra-flat epitaxy ready GaSb substrates: requirements for MBE grown advanced infrared detectors

M. J. Furlong, R. J. Martinez, S. Amirhaghi, B. Smith, A. Mowbray, Wafer Technology Ltd. (United Kingdom)

In this paper we describe the crystal growth and surface characterisation of ultra-flat 4” GaSb substrates suitable for the epitaxial deposition of advanced infrared detectors. Results will be presented on the production of single crystal 4” GaSb ingots grown by a modified version of the liquid encapsulated Czochralski (LEC) technique, supported by the analysis of bulk material quality by dislocation density assessments. This study will also describe how various techniques were used to characterise the quality of the bare substrate. Surface oxide properties of the GaSb substrates will be characterised by spectroscopic ellipsometry (SE). Bow, Warp and Total Thickness Variation (TTV) data will be presented for batches of 4” wafers processed on a volume multiwafer-type polishing platform, demonstrating the consistent delivery of < 5 µm flatness against these parameters. This study will conclude with a ‘blueprint’ for the manufacture of large diameter GaSb substrates, this defining the requirements for the production use of GaSb within a commercial epitaxial wafer foundry.

8353-41, Session 6

Dark current modeling of Type II superlattice diodes

A. Rogalski, Military Univ. of Technology (Poland)

No abstract available

8353-91, Session 6

Competing technology for high-speed HOT-IR-FPAs

M. Razeghi, Northwestern Univ. (United States)

GaSb/InAs type-II superlattice is an ideal material for realization of high operating temperature (HOT) infrared detectors due to low Auger recombination rate in this material. The recent developments of HOT detectors at Center for Quantum Devices will be reviewed in this talk. It will be shown that with introduction of a tunneling barrier to suppress the tunneling current and increasing the doping level of the active region to suppress diffusion current, more than an order of magnitude improvement in the electrical performance was achieved. At 150K, R0A of 5100 Ω.cm2and specific detectivity of 1.05 x 1012cm.Hz0.5/W is demonstrated for a 50% cut-off wavelength of 4.2µm. Assuming 300K background temperature and 2π field of view, the performance of the detector is background limited up to 180K. FPAs were fabricated using this design and infrared imaging using f/2.3 optics and an integration time of 10.02 s demonstrates a noise equivalent temperature difference of 11mK at operating temperatures below 130K.

8353-43, Session 7

Formation of GaN film on Si for microbolometer

Y. S. Lee, D. Kim, J. Kim, Kyungpook National Univ. (Korea, Republic of); Y. Jung, Kyungju Univ. (Korea, Republic of); J. Lee, Kyungpook National Univ. (Korea, Republic of)

1. Formation of GaN film on Si substrate: The successful growth of thin single or polycrystalline GaN film on Si can be a good semiconductor bolometric material. And the multi wavelength detecting systems with GaN based compounds including UV detector, power devices, amplifier with GaN and AlGaN MOSFET, HEMT and etc can be possible. We obtained single crystal GaN layer on Si(111) with graded-AlGaN buffer layers with FWHM(full width at half maximum) of ~500.

2. Analysis of GaN films and its evaluation on bolometric properties: Acquired GaN films were analyzed from the PL spectrum and demonstrated its crystal quality by the fabrication of MOSFET. The bolometric characteristic of TCR and noised characteristic will be analyzed.

3. Application of infrared sensor : we investigated multi wavelength detection possibility including infrared ray. Through result of calculation of microbolometer for 50 ×50, It will be described that the NETD(noise equivalent temperature difference) below 100mK is obtainable.

8353-44, Session 7

Novel uncooled detector based on gallium nitride micromechanical resonators

M. Rais-Zadeh, V. J. Gokhale, S. Yu, Univ. of Michigan (United States)

Wide band gap semiconductor materials such as GaN have tremendous potential for sensing applications in high power, high temperature and high frequency regimes. Based on the commercial success of GaN for

high electron mobility transistors (HEMTs), there has been an effort to use the 2D electron gas as a transduction layer for sensing. GaN has enabled solar blind UV detectors insensitive to wavelengths more than 285nm, based on its 3.39 eV band gap transition. At the same time, GaN exhibits a strong pyroelectric effect, which in conjunction with an absorber layer, can be used to absorb radiation thermally in a wider band not limited to the optical absorption spectrum of GaN. IR incident radiation is thermally absorbed by the CNT based absorber on GaN, causing a thermal gradient across GaN layer. The pyroelectric effect manifests as a release of charges at the GaN surface with increased temperature, which causes degradation in the filter out-of-band rejection. In addition, the resulting pyroelectric field induces a piezoelectric strain which reduces the resonant frequency. Therefore, IR radiation can be detected by tracking the change in the resonance behavior of the GaN micromechanical resonator. The advantage of resonant pyroelectric detectors over conventional microbolometers is that they offer higher signal to noise ratio thanks to intrinsic filtering achieved in the resonant device, thus can offer better NEDT values at room temperature.

8353-45, Session 7

Silicon-based nanobolometer for multispectral room temperature IR detection

H. Lee, Tanner Research, Inc. (United States)

Because of the low energy photons, IR detection typically requires the use of exotic and expensive narrow bandgap materials in cryogenic environment in order to generate photocurrent signal. Microbolometer technology, on the other hand, converts incident IR photons into thermal energy and is capable of room temperature detection. However, it absorbs heat from broad spectrum and makes it difficult for multi-spectral detection.

Tanner is developing a radically new detection technology termed 'Nanobolometer' with the goal of building a Si based room temperature multi-spectral IR detector covering the spectrum from NIR to LWIR. An added advantage is that UV-Vis detection can also be easily integrated since it shares the same Si substrate making our device a UV-LWIR multi-spectral detector.

The enabling technology is the optical resonance of nanoparticle array which are embedded in the gate oxide of a MOSFET device. As IR raditation is resonantly absorbed by the particle array, strong E-field is generated around the individual particles (particle plasmons). This enhanced E-field assists in the increase in the amount of leakage current through the gate from the channel current; The amount of leakage current is proportional to the E-field around the particles which in turn is proportional to the intensity of incident IR radiation. Therefore, we measure the change in the channel current as the signal. Our preliminary experimental result showed a detection response at 1.5 um wavelength.

We will present the theory and working principle of our Nanobolometer technology. We will also present the current status of our effort in developing SWIR/MWIR/LWIR detector using the same technology.

8353-46, Session 7

Development of microbolometer with high fill factor and high mechanical stability by shared-anchor structure

T. Kim, K. Kyung, J. H. Park, Y. S. Kim, S. K. Lim, K. Kim, T. Lee, K. Lee, National Nanofab Ctr. (Korea, Republic of); C. Welham, COVENTOR Europe (France); H. Y. Kim, National Nanofab Ctr. (Korea, Republic of)

Recent IR imaging sensors need a small-sized pixel for high resolution as well as for small form factor. For the effective pixel design with high fill factor, the anchor and leg area should be minimized because these spaces proceed to low thermal resolution by reducing IR absorption area. This paper presents most efficient way to use these spaces by shared-anchor structures, and presents how these designs are evaluated. Generally, the microbolometer has at least 2 anchors and 2 legs for 4/λ resonant cavity structure. When the neighboring pixels share a same anchor, this area will be also shared by pixel to pixel space. As a result, it can be possible to make a one anchor per unit pixel by shared-anchor structure. Unit pixel has 4 legs, only 2 legs of which have electrical conductive layer to make electrical resistance independent of neighboring pixels. The fill factor increases 10% more than that of unshared-anchor design. Through the FEM simulation, the proposed design has more promising results than unshared-anchor design in terms of the mechanical, electrical and thermal characteristics.

Amorphous-silicon based microbolometer with 4 anchors and 4 legs have been fabricated with 64x64 arrays of 25um pixel size. Mechanical flatness of shared-anchor structure is enhanced compared to unshared-anchor design. Electro-thermal properties of the microbolometer are measured by high speed I-V measurement technique in vacuum condition. Thermal time constant and thermal conductivity are measured to 10msec and 3.8e-8 W/K for a shared-anchor design. Responsivity of proposed design is enhanced from 1.08e+5 V/W to 1.23e+5 V/W due to the increase of fill-factor compared to unshared-anchor. There are no mechanical, electrical and thermal crosstalk problems with adjacent pixels. It shows that the proposed pixel design is very useful in the development of small sensor for mobile applications.

8353-105, Session 7

Uncooled silicon germanium oxide ($SixGe_{1-x}Oy$) thin films for infrared detection

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This paper presents a detailed characterization of silicon germanium oxide (SixGeyO1-x-y) thin films for uncooled infrared detection. The composition ratio of Si, Ge, and O were varied and their influence on TCR, resistivity and electrical noise were determined. SixGeyO1-x-y films were grown by RF magnetron sputtering from two targets Si and Ge simultaneously in an oxygen and argon environment at room temperature and at 4 mTorr pressure, and with a thickness around 300 nm. The results demonstrated that high TCR and low resistivity can be achieved using various compositions. The lowest measured resistivity and the corresponding TCR were 59.8 ohm-cm and -2.202 %/K respectively, using Si0.1356Ge0.8382O.0266 for film deposited at room temperature, whereas the highest achieved TCR and the corresponding resistivity at room temperature were –5.41 %/K, and 3.16×103 ohm-cm, respectively, using Si0.039Ge0.875O0.086 for films deposited at room temperature. The activation energy (Ea) of films with highest TCR was calculated from the slope of Arrhenius plot with a value of 0.4216 eV. We have also observed that for a fixed oxygen concentration of 3%, 4%, 5%, or 6%, TCR magnitude decreases and the resistivity increases as the Si concentration increases. As the fixed O2 concentration increases to 7%, 8%, 9%, or 10%, both TCR magnitude and resistivity increase with increasing Si concentration. The electrical noise of the deposited films were measured but not optimized. We have also measured the film structure as a function of oxygen and silicon content using X-ray Diffraction (XRD). The films appear to be amorphous.

8353-47, Session 8

Uncooled detector development at Raytheon

S. H. Black, Raytheon Co. (United States)

Following the "Moore's law of Imaging", the format of uncooled focal plane arrays continues to grow, while at the same time the pixel pitch and cost continue to shrink. In this paper we will report on the first mega-pixel uncooled imager. We will also report on work to reduce the pixel pitch to enable small form factor, high-definition uncooled imagery. Additionally, work to further reduce the cost of microbolometer packaging will be presented.

8353-49, Session 8

Easy to use uncooled ¼ VGA 17 µm FPA development for compact and low-power systems

J. M. Tissot, P. Robert, ULIS (France)

The high level of accumulated expertise by ULIS and CEA/LETI on uncooled microbolometers made from amorphous silicon enables ULIS to develop ¼ VGA IRFPA formats with 17µm pixel-pitch. ROIC architecture will be described where innovations are widely on-chip implemented to enable an easier operation by the user. The detector configuration is driven by a standard I²C link. Like most of the visible arrays, the detector adopts the HSYNC/VSYNC free-run mode of operation driven with only one master clock (MC) supplied to the ROIC which feeds back pixel, line and frame synchronizations. On-chip PROM memory for customer operational condition storage is available for detector characteristics.

Low power consumption has been taken into account and less than 70 mW is possible in analog mode at 60 Hz and < 175 mW in digital mode (14 bits). A wide electrical dynamic range (2.4V) is maintained despite the use of advanced CMOS node. The specific appeal of this unit lies in the high uniformity and easy operation it provides. The reduction of the pixel-pitch turns this TEC-less ¼ VGA array into a product well adapted for high resolution and compact systems.

Electro-optical performances of this IRFPA will be presented. We will insist on NETD trade-off with wide thermal dynamic range, as well as the high characteristics uniformity and pixel operability, achieved thanks to the mastering of the amorphous silicon technology coupled with the ROIC design. This technology node associated with advanced packaging technique, paves the way to compact low power system.

8353-50, Session 8

2-million-pixel SOI diode uncooled IRFPA with 15µm pixel pitch

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The number of pixels in IRFPAs used for various applications is growing year by year. In addition, demand for high resolution image is becoming stronger. The pixel pitch reduction to less than 17µm and the stitching technology are key issues for manufacturing of ultra large format IRFPAs exceeding 1 million pixels. Regarding the former, our proposed 2-in-1 SOI diode enabled us to shrink the pixel pitch beyond 17µm [1]. Furthermore, as for the latter, we developed the uncooled IRFPA stitching technology and verified its establishment with XGA IRFPA fabrications utilizing our existing pixel pitch technology [Unpublished]. The stitching technology allows physical merger of multiple design structures onto a wafer during the photolithography process and frees our chip size design from limitation of the field size of the conventional stepper.

In this paper, we report development of 2 million pixel, that is, 2000 x 1000 array format, SOI diode uncooled IRFPAs with 15µm pixel pitch, in the combination of the 2-in-1 SOI diode technology and the uncooled IRFPA stitching technology. The chip size is 40.3 mm x 24.75 mm. 10 series diodes are arranged in a 15µm pixel. In spite of increase of number of pixels to 2 millions, a frame rate of 30 Hz, which is the same frame rate of our former generation (25µm pixel pitch) VGA IRFPA, can be supported, by the adoption of 4 outputs. NETDs are designed to be 60 mK(f/1.0, 15 Hz) and 84 mK(f/1.0, 30 Hz), respectively and a τth is designed to be 12 msec. The ongoing measurements of the chips have clarified that the temperature coefficient of the SOI diode forward voltage (dVf/dT) of the pixels is as large as 14.7 mV/K, which has been confirmed to be identical to the designed value. Other evaluated data will be demonstrated in detail in the conference.

[1] D. Takamuro et al., "Development of new SOI diode structure for beyond 17µm pixel pitch SOI diode uncooled IRFPAs," Proc. SPIE Vol. 8012, 80121E, 2011.

8353-51, Session 8

SCD µ-bolometer VO_x infrared high-end detector development

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A new generation of high-performance uncooled detectors, 17 & 25 µm pitch with improved sensitivity and extended spectral response were developed recently by SCD. This development brings the uncooled technology very close to the performance of traditional cooled LWIR arrays. and enables a new range of applications. For long distance observation applications, we have demonstrated the use of the very high sensitivity 25 µm pitch detector, with F/2.4, and for situation awareness applications, we present the new wide band detector, where detector absorption is optimized to both the MWIR & LWIR bands.

Moreover, in this work we describe the progress of 17µm pixel different array formats (QVGA, VGA and XGA) development programs. This is targeting a range of applications, starting from medium performance and low Size, Weight and Power (SWaP) applications, up to a high-end performance application.

8353-52, Session 8

Current progress on pixel level packaging for uncooled IRFPA

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Vacuum packaging is definitely a major cost driver for uncooled IRFPA and a technological breakthrough is still expected to comply with the very low cost infrared camera market. To address this key issue, CEA-LETI is developing a Pixel Level Packaging (PLP) technology which basically consists in capping each pixel under vacuum in the direct continuation of the wafer level bolometer process. Previous CEA-LETI works have yet shown the feasibility of PLP based microbolometers that exhibit the required thermal insulation and vacuum achievement.

CEA-LETI is still pushing the technology which has been now applied for the first time on a CMOS readout circuit. The paper will report on the recent progress obtained on PLP technology with particular emphasis on the optical efficiency of the PLP arrangement compared to the traditional microbolometer packaging. Results including optical performances, aging studies and compatibility with CMOS readout circuit are extensively presented.

8353-53, Session 9

An information-theoretic perspective on the challenges and advances in the race toward 12µm pixel pitch for megapixel uncooled infrared imaging

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This paper describes, from an information-theoretic perspective, how using pupil function engineering can enable to compensate for the optical resolution and noise sensitivity problems caused by shrinking pixel geometry in microbolometer FPAs. Pupil function engineering is a

computational imaging approach in which the image acquisition process is shared between the optics and post-capture digital processing (cf. encoding-decoding scheme).

We start by briefly reviewing the key technological breakthroughs in a-Si thin-film technology and pixel microstructure design. We discuss how thermal time constant, detector sensitivity and intra-scene dynamic range are maintained, and we stress the importance of these parameters on the noise performance of microbolometer pixels.

Next we introduce a rigorous and unified framework based on the concept of optical (communication) channel capacity to both explain and analyze the imaging performance tradeoffs between spatial bandwidth, FOV, DOF, SNR and downscaling of the camera system. We derive a scaling law, showing that an information "bottleneck" - also known as limited space-bandwidth product - occurs at the lens level when shrinking pixel size, due to both geometrical aberrations and the light diffraction effect.

Finally, we present the theorem of conservation of information capacity and its application in the context of pupil function engineering to improve the fundamental imaging tradeoffs of uncooled infrared cameras via space-bandwidth adaptation. By using the suggested framework, the performance of various wavefront encoding-decoding techniques is compared, and experimental results are presented to demonstrate the ability of computational imaging.

8353-54, Session 9

Flexible readout and integration sensor (FRIS): a bio-inspired, system-on-chip, event-based readout architecture

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The advanced imagers' team at JHU APL and ECE has been advocating and developing a new class of sensor systems that address key performance bottlenecks but is sufficiently flexible to allow optimization for associated cost and size, weight, and power (SWaP) for different applications and missions. A primary component of this approach is the bio-inspired system-on-chip architecture which at the system level, relies on an event based sampling scheme where only pixels within a programmable range of photon flux rates are output. At the pixel level, a one bit oversampled analog-to-digital converter together with a decimator allows for the quantization of signals up to 26 bits. Furthermore, digital non-uniformity correction of both gain and offset errors is applied at the pixel level prior to readout. We fabricated a prototype array in a standard 90nm CMOS process. The array is subdivided into four quadrants where we test different frontend circuits for the potential application to long wave infrared focal plane arrays. We report test results for the various frontend circuits including signal to noise ratio, power, and dynamic range. Tests were performed at room and cryogenic temperatures.

8353-55, Session 9

ADMIRE: a locally adaptive single-image, non-uniformity correction and denoising algorithm: application to uncooled IR camera

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This paper deals with the non-uniformity (NU) of a thermal infrared camera. The readout technique of CCD devices leads to a structured row pattern in images. This is a serious limitation to both civilian and military applications as it severely degrades the image quality and cannot be compensated by classic denoising algorithms.

For uncooled cameras the difficulty is increased as the detector response evolves with time. A correction is so much needed, that in many devices a flap closes within 30s and allows a partial calibration. This interrupts the image flows, which can be calamitous. Therefore a good NU algorithmic correction is a key factor in ensuring the best image quality and the robustness of the downstream applications.

Following [5] we propose a new way to correct for the NU, eliminate the row-like noise and the noise present in infrared-type images at once. This method works on static images and needs no registration nor voluntary camera motion [1], [4].

The proposed method uses an hybrid scheme including an automatic locally adaptive version of [5] and a state-of-the-art image denoising method. The proposed solution exhibit a significant improvement on [5]. This kind of scheme permits to efficiently correct for a fully non-linear NU and the noise using only one image and is, to our knowledge, completely new in infrared context imagery.

This method is compared to the state-of-the-art total-variation [2] and to [5], on real NU infrared and simulated NU images. The strength of this approach lies in its simplicity, low computational cost, it needs no test-pattern nor calibration and doesn't produce any ghost-artifacts [3].

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[4] S.N. Torres and Majeed M. Hayat. Kalman ltering for adaptive nonuniformity correction in infrared focal-plane arrays. J. Opt. Soc. Am. A, 20(3):470-480, 2003.

[5] Y. Tendero, J. Gilles, S. Landeau, J.M. Morel. Efficient single image non-uniformity correction algorithm. SPIE D&S, Toulouse (FR), September 2010

8353-56, Session 10

Thales cryogenics rotary cryocoolers for HOT applications

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Thales Cryogenics has an extensive background in delivering reliable linear and rotary coolers for military, civil and space programs. Recent work carried out at detector level enable to consider a higher operation temperature for the cooled detectors. This has a direct impact on the cooling power required to the cryocooler. In continuation of the work presented last year, Thales cryogenics has studied the operation and optimization of the rotary cryocoolers at high cold tip temperature.

In this paper, the performances of the Thales Cryogenics rotary cryocoolers at elevated cold tip temperature will be presented. From these results, some tradeoffs can be deducted in order to combine correct operation of the cryocooler on all the ambient operational range and maximum efficiency of the cryocooler. These tradeoffs and the impact on MTTF of elevated cold tip temperature will be presented and discussed.

In correlation with the increase of the cold operation temperature, the cryocooler input power is significantly decreased. As a consequence, the cooler drive electronics own consumption becomes relatively important and must then be evaluated in order to minimize global input power to the cooling function (cryocooler and cooler drive electronics). Thales Cryogenics has developed a new drive electronics optimized for low input power requirements. The main characteristics and performances of this new drive electronics, compatible with the full range of Thales Cryogenics rotary coolers, will be described.

Thales cryogenics is now able to propose an efficient cooling function for application requiring a high cold tip temperature including a range of tuned rotary coolers.

8353-57, Session 10

Update on MTTF figures for linear and rotary coolers of Thales cryogenics

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Thales Cryogenics has an extensive background in delivering linear and rotary coolers for military, civil and space programs. During the last years several technical improvements have increased the lifetime of all Thales coolers resulting in significantly higher MTTF's. In this paper not only updated MTTF values for most of the products in our portfolio will be presented but also the methodology used to come to these reliability figures will be explained.

The differences between rotary and linear coolers will be highlighted including the different failures modes influencing the lifetime under operational conditions. The updated reliability figures are not only based on the extended test experiences for both rotary and linear coolers but also combine Weibull analysis, failure mode identifications, various types of lifetime testing and field results of operational coolers. Also the impact of the cooler selection for typical application will be outlined.

The updated reliability approach will enable a much better tradeoff for cooler selections in those applications where MTTF and a correct reliability assessment is one of the key elements. Improving on the cooler selection and an increase of insight in cooler reliability will result in a higher uptime and operability of equipment, less risk on unexpected failures and lower costs of ownership.

8353-58, Session 10

Compact high-efficiency linear cryocooler in single-piston moving magnet design for HOT detectors

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State of the art Mid Wave IR-technology has the potential to rise the FPA temperature from 77K to 130-150K (high operation temperature HOT). Using a HOT FPA will significantly lower SWaP and keep those parameters finally dominated by the employed cryocooler. Therefore compact high performance cryocoolers are mandatory.

AIM has developed the SX040 cooler, optimized for FPA temperatures of about 95K (presented at SPIE 2010). The SX040 cooler incorporates a high efficient dual piston driving mechanism resulting in a very compact compressor of less than 100mm length.

Higher compactness - especially shorter compressors -can be achieved by change from dual to single piston design. The new SX030 compressor has such a single piston Moving Magnet driving mechanism resulting in a compressor length of about 60mm. Common for SX040 and SX030 family is a moving magnet driving mechanism with coils placed outside the helium vessel. In combination with high performance plastics for the piston surfaces this design enable lifetimes in excess of 20.000h MTTF.

Because of the higher FPA temperature and a higher operating frequency also a new displacer needs to be developed. Based on the existing ¼" coldfinger interface AIM developed a new displacer, optimized for a FPA temperature of 140K and above.

This paper gives an overview on the development of this new compact single piston cryocooler. Technical details and performance data will be shown.

8353-59, Session 10

RICOR's rotary cryocoolers development and optimization for HOT IR detectors

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The world growth in research and development with High Operating Temperature IR detectors impels the development process and optimization of rotary cycoolers. The design aspects of Size Weight and Power and the tradeoffs between them, took into considerations during the development process in order to optimize IDDCA for future hand held thermal sights.

The paper will present optimization tests results done for rotary crycoolers at the range of 120 - 200K FPA temperature and also will review the development activities that will be implemented in order minimize "Idle electronic and mechanical losses" hence minimize the regulated power consumption

As a result of the new approach with Rotary crycoolers for HOT detectors, the improvement in the reliability analyzed and will be reported in the paper.

8353-60, Session 10

Linear cryogenic coolers for HOT infrared detectors

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In spite of a wide spreading the uncooled night vision technologies, the cooled systems are still known to be superior in terms of working ranges, resolution and ability to distinguish/track fast moving objects in dynamic infrared scenes.

Recent technological advances allowed development and fielding of HOT (up to 200K) infrared detectors showing performances typical for their 77K predecessors. The direct benefits of using such high temperature detectors are the lowering of the optical, cooling and packaging constraints resulting in simplified system design relying on smaller and cost effective optics, electronics and mechanical cryocooler.

Based on joint vision of prospective ultra-compact, lightweight, power saving, acoustically and dynamically quiet cryogenically cooled infrared imager, the authors are formulating the basic requirements and explore a design concept of the microminiature Stirling cryogenic cooler with emphasis on extended life, short cooldown times and high elecrto-mechanical performance.

The authors are revealing the experimental outcomes of the feasibility study testing and discuss further downscaling options. Along with these lines they are discussing the packaging issues including heatsinking, noise and vibration control.

8353-61, Session 10

Experimental demonstration of cryocooler electronics with multiple mechanical cryocooler types

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This paper demonstrates experimentally a single cryocooler control electronics (CCE) design successfully driving several very different cryocoolers and simulated cryocooler loads, including a space pulse tube cryocooler, long life tactical Stirling coolers, and even a simulated reverse turbo Brayton (RTB) cryocooler load. The CCE is an early brassboard version of low cost, radiation hard cryocooler electronics being developed primarily for cost-constrained, but nevertheless mission critical military and civilian spaceborne applications. This design is also applicable for tactical applications which seek to support multiple cryocooler types and/or vendors with a given CCE. The CCE provides high efficiency DC-to-AC conversion, automated cool down, and precision temperature control. Experimental results for a low frequency input current ripple filter, which is of interest for reciprocating Stirling and pulse tube type coolers to reduce conducted emissions back onto the spacecraft power bus, are also presented. The combined results demonstrate convincingly that this CCE design is broadly supportive of a wide range of thermodynamic-mechanical cryocooler units (TMUs) for a subsequently broad range of payloads and missions.

8353-62, Session 11

Common aperture multispectral optics for military applications

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With the recent developments in multi-spectral detector technology the interest in common aperture, common focal plane multi-spectral imaging systems is increasing. Such systems are particularly desirable for military applications where increased levels of target discrimination and identification are required in cost-effective, rugged, lightweight systems.

During the optical design of dual waveband or multi-spectral systems, the options for material selection are limited. This selection becomes even more restrictive for military applications as material resilience and thermal properties must be considered in addition to colour correction.

In this paper we discuss the design challenges that lightweight multi-spectral common aperture systems present along with some potential design solutions. Consideration will be given to material selection for optimum colour correction as well as material resilience and thermal correction. This discussion is supported using design examples that are currently in development at Qioptiq.

8353-64, Session 11

Tailored thermal emission from sub-wavelength diffractive optical elements

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We explore the spectral and angular selectivity of near surface normal emission from grating modified metallic surfaces and their ultimate potential for application as narrow-band gain enhancement components in the development of advanced infrared focal plane arrays. The developed photonic microstructures exhibit tailored angular spectra in the long wavelength infrared, thus providing gain through spectral and angular selectivity. Modification of the material and structural properties of the diffractive optical element enables sub-pixel tuning of the spectral and angular responses of the device allowing for further development of planar gain components for development of advanced focal plane arrays in the long wavelength infrared. The planar nature of the developed components leaves them immune to fabrication issues that typically plague thin film interference filters used for similar applications in the infrared, namely, deposition of multiple low-stress quarter-wavelength films and modification of the film thicknesses for each pixel. The solution developed here presents the opportunity for sub-pixel modification of the spectral, angular, and polarization response of the provided gain enhancement leading to an efficient, agile gain component suitable for direct integration with commercially available focal plane array technologies via standard fabrication techniques. We will discuss the theoretical and experimental development of the described components and compare the results to the current state-of-the-art.

8353-65, Session 11

Low-reflecting DLC coating on IR substrates

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Diamond Like Carbon (DLC) or Hard Carbon (HC) single layer coatings on optical substrates are commonly used. As a single layer, the resulting average reflection in different spectral ranges (Example: about 2.5% in the 3-5µ region) needs improvements. We propose multilayer coatings having a DLC upper layer applied on Si, Ge and other materials. These coatings result in average reflection of less than 0.5% in either the 3.4-5µ or the 8-11.5µ regions. The average transmittance in these regions is more than 97%. The durability is comparable to single layer DLC coatings. These coatings are suitable to front surface FLIR lens assemblies. The effect on the performance of a zoom lens assembly and the reduction of the Narcissus effect is shown.

8353-66, Session 11

Multi-field of view see-spot optics

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Imaging from the 1-5 micron spectral band on a single focal plane array provides a system with the ability to see both traditional MWIR imager, combined SWIR/MWIR imagery, and perhaps most importantly, the ability to see laser range finders and designator wavelengths. However, unless an all reflective system is used, achieving this capability is very challenging. This paper discusses the design and development of a multi-FOV optical system with the capability to image across the 1-5 micron spectral band utilizing a combination of reflective and refractive components.

8353-63, Session 12

Planar integrated plasmonic mid-IR spectrometer

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The convergence of silicon photonics and infrared plasmonics allows compact, chip-scale spectral sensors. We report on the development of a compact mid-IR spectrometer based on a broad-band IR source, dielectric waveguides, a transformer to convert between waveguide modes and surface plasmon polaritons (SPP), an interaction region where analyte molecules are interrogated by SPPs, an array of ring resonators to disperse the light into spectral components, and photodetectors. The mid-IR light source emits into a dielectric waveguide, leading to a region that allows coupling of the incident photons into SPPs. The SPPs propagate along a functionalized metal surface within an interaction region. Interactions between the propagating SPP and any analytes bound to the surface increase loss at those wavelengths that correspond to the analyte vibrational modes. After a suitable propagation length the SPP will be coupled back into a dielectric waveguide, where specific wavelength components will be out-coupled to detectors by an array of ring resonators. We have selected a 3.4 micron LED as the IR source, based on both cost and performance. Initial experiments with circular waveguides formed from GLSO glass include measurement of the loss per mm. Electrodynamic simulations have been performed to inform the eventual Si taper design of the proposed photonic/plasmonic transformer. The SPP propagation length necessary for a discernable change in the signal due to absorption in the interaction region has been estimated to be on the order of 1 mm, well within the bounds of calculated propagation lengths for SPPs on Au.

8353-67, Session 12

Integration of wide field-of-view imagery functions in a detector dewar cooler assembly

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Today, both military and civilian applications require miniaturized optical systems in order to give an imagery function to vehicles with small payload capacity. After the development of megapixel focal plane arrays (FPA) with micro-sized pixels, this miniaturization will become feasible with the integration of optical functions in the detector area. In the field of cooled infrared imaging systems, the detector area is the Detector-Dewar-Cooler Assembly (DDCA). A dewar is a sealed environment where the detector is cooled on a cold plate. We show in this paper that wide field of view imagery functions can be simply added to the dewar. We investigate two ways of integration and make two demonstrators. The first one called FISBI consists in replacing the window by a fish-eye lens and in integrating a lens in the cold shield. This optical system has a field of view of 180°. The second one, called IR-Cam-on-Chip, consists in integrating the optics directly on the focal plane array. This optical system has a field of view of 120°. The additional mass of the optics is sufficiently small to be compatible with the cryogenic environment of the DDCA. The performance of these cameras will be discussed and several evolutions of these cameras will be introduced too.

8353-68, Session 12

Infrared focal plane array with a built-in stationary Fourier-transform spectrometer: recent technological advances

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A concept of Fourier-transform infrared spectrometer integrated on a focal plane array (FTIR-FPA) has been developed for very fast acquisition of spectral signatures. The basic idea is to use the upper surface of the focal plane array as the first mirror of a two-wave interferometer, which creates interference fringes directly inside the active layer. Two technologies have been developed.

In a "monolithic" version of our FTIR-FPA concept, the cavity is made by grinding the substrate to the shape of a wedge. In a "hybrid" version, the cavity is made by hybridizing a Silicon plate just above the focal plane array. The angular acceptance is lower than for the monolithic device, but it is easier to obtain rectilinear fringes, and their contrast is higher. Besides, the manufacturing process is less harmful for the focal plane array, and very low optical path differences can be reached.

We focus here on two hybrid FTIR-FPAs, one in the MWIR domain and one in the SWIR domain. Both are made with a Mercury-Cadmium-Telluride focal plane array. The technological process to manufacture these spectrometers is described, as well as the processing chain to convert the raw interferograms into spectra. Experimental results and field tests are presented.

8353-70, Session 12

Laser designator protection filter for see-spot thermal imaging systems

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Thermal imaging systems such as are designed for applications requiring not only high-resolution thermal imaging, but also the ability to see the aiming point of a laser designator.

The use of laser 'see spots' to assist in target identification and tracking can unintentionally result in a laser beam reflected back into the sensor, leading to transient dazzling or permanent damage of the sensor. This scenario can lead to non-operation thermal imaging system.

The need to protect the system from the same kind of laser it is required to observe, is presenting an engineering challenge. The usual spectral filter solution is obviously not suitable in this case, since it will block completely the same laser wavelength range required for designation.

We propose a novel passive solid-state threshold-triggered Wideband Protection Filter (WPF) that blocks the transmission only if the power exceeds a certain threshold. As opposed to fixed spectral filters, which permanently block only specific wavelengths, the wideband filter is clear at all wavelengths until hit by damaging light. At input power below threshold, the filter has high transmission over the whole spectral band. However, when the input power exceeds the threshold power, transmission is decreased dramatically. This decreased transmission is limited to the hitting point of impingement, where the spot becomes permanently opaque and remains so even after a long exposure to high power. The WPF can provide a suitable solution for thermal imaging systems, which are open for the wavelength region of the laser designator.

8353-71, Session 12

Passive athermalization of two-lens designs in 8-12micron waveband

N. Schuster, Umicore Electro-Optic Materials (Belgium); J. Franks, Umicore Coating Services (United Kingdom)

Passive athermalization has become a key-technology for automotive and other outdoor applications using modern uncooled 25 and 17 micron bolometer arrays. For high volume applications, passive athermalized optical designs with only two lenses reduce costs and require a careful choice of lens materials.

GASIR possesses inherent passive athermalization properties. High resolution, two lens designs for different field angles are presented. The lens designs use aspherics and diffractive structures. Resolution values and their variation with temperature are given.

The allowable degradation of MTF over temperature depends on the application. A proposal to quantify the athermalization is defined. More generally, the admissible residual change of image position over temperature is calculated depending on F-number. Also included is a discussion of thermal drift of focus equation discloses methods for passive athermalization.

Several measures to maintain passively the admissible residual change of image position over temperature are discussed for a demanding narrow field of view example. These include mechanical methods with different kinds of movement: only first lens, only second lens and both lenses. The shortest compensation mechanism is achieved by moving the lens with the biggest power.

The impact of admissible MTF-reduction on the compensation mechanism is shown.

Optical methods to reduce residual change of image position over temperature of narrow field of view lens example are also discussed. Intelligent choice of material can significantly reduce the length of mechanical compensation mechanism.

8353-72, Session 12

Advantages of using engineered chalcogenide glass for color corrected, passively athermalized LWIR imaging systems

S. W. Sparrold, K. Schwertz, A. Bublitz, Edmund Optics Inc. (United States)

Long wave infrared (LWIR) optical systems are prone to defocus with changing temperature. IR refractive materials are more thermally sensitive compared to conventional visible glass due to their larger therm-optic coefficients. LWIR systems can be designed to be passively athermal (little or no change to focus with varying temperatures). Chalcogenide glasses provide additional material choices for IR lens designers. In particular AMTIR5, has been engineered so its therm-optic coefficient matches the coefficient of thermal expansion of aluminum, allowing for an athermal singlet. This paper explores the benefits of using engineered chalcogenide glass for color corrected, passively athermal systems.

Initially, we present color corrected and passively athermal doublets that are designed with different materials and / or diffractive surfaces. Their thermal and color performance are cataloged for axial beams only. These are intended to be starting components, which readers may then insert into common design forms, such as Petzvals, Double Gauss, Telephoto and Inverse Telephoto.

An F/1, 20° full field of view, aspheric Petzval lens design form is explored and the MTF is evaluated for -50°C to 85°C in an aluminum housing. From this design, we explore the tradeoffs between using chalcogenide versus crystalline materials, diffractive versus pure refractive surfaces, and engineered chalcogenide (AMTIR5) versus “catalog” materials.

8353-73, Session 12

Qualification and metrology for US-produced chalcogenides

N. Carlie, SCHOTT North America, Inc. (United States)

Schott is melting and producing chalcogenide components at it’s Duryea, PA facility to target the US defense market. Schott’s advanced metrology capabilities allow for a full characterization of chalcogenide material properties to help accurately predict an infrared systems performance. Material properties would include refractive index, index homogeneity, inclusion level and dn/dt.

8353-74, Session 12

Material trades between Be, SiC, and VQ aluminum for tactical systems: update referencing the current state-of-the-art

C. J. Duston, T. Hull, L-3 Integrated Optical Systems Division (United States)

We consider trade parameters and relative advantages of beryllium, silicon carbide and Visible Quality (VQ) aluminum in terms of the currently available optical finishing characteristics, as well as their physical and thermal characteristics. Both bare and EN clad beryllium, and bare and Si clad SiC are considered. Each of these materials is routinely processed at L-3 Integrated Optical Systems Division (Tinsley, SSG, Brashear). Combinations of constraints, environments, mount options and required performance may affect the choice between these materials. Guidelines are provided which may help a designer evaluate choices based on the current state of the art.

8353-75, Session 12

Mid-spatial frequency matters: examples of the control of the power spectral density and what that means to the performance of imaging systems

T. Hull, L-3 Integrated Optical Systems Division (United States) and The Univ. of New Mexico (United States); M. J. Riso, J. M. Barentine, L-3 Integrated Optical Systems Division (United States)

We will discuss mid-spatial frequency (MSF) optical surface errors, and how they affect optical performance of an optical system, including contrast, ensquared energy and pixel cross-talk. MSF errors will be represented in terms of Power Spectral Density (PSD), and examples will be discussed where PSD is well controlled and poorly controlled. The MSF associated with optics requiring high aspheric departure are historically especially difficult to control. We will show recent examples of PSDs of aspheric mirrors, sometimes with very challenging aspheric departure or other attributes, as routinely finished Tinsley, and suggest ways the designer can effectively specify an optic for smoothness.

8353-142, Session 12

Advanced in shutter drive technology to enhance man-portable IR cameras

D. W. Durfee, CVI Melles Griot (United States)

With an emphasis on highest reliability, military IR imagers have traditionally used simplest-possible shutters and field-proven technology. Most commonly, solenoid drive and simple, single-step rotary or linear magnetic actuators have been used with good success. However, several newer shutter drive technologies offer major benefits in size and power reduction, enabling man-portable imagers that are more compact, lighter, and more durable.

This paper will discuss various improvements in shutter and shutter drive technology, which enable smaller and more power-efficient imagers. Topics will transition from single-step magnetic actuators whether bistable and spring return), multi-stepping magnetic drives (rotary and linear), spring-return vs. latching vs. balanced systems for blade position shock-resistance, motor and geared motor drives, ultra-flat and planar shutters, and ultrasonic drives, as well as associated driver electronics. It will highlight key benefits of each approach and associated performance tradeoffs pertinent to man-portable portable military systems. It will also address some of the options in shutter blade geometry and drive linkage approach, as it pertains to compactness of the shutter and cost/per

8353-76, Session 13

Low-noise GHz bandwidth 16-channel photoreceivers for lidar imaging applications

X. Bai, P. Yuan, P. A. McDonald, J. C. Boisvert, J. J. Chang, R. L. Woo, E. L. Labios, R. Sudharsanan, Spectrolab, Inc., A Boeing Co. (United States); M. A. Krainak, G. Yang, X. Sun, W. Lu, NASA Goddard Space Flight Ctr. (United States)

Future NASA light detection and ranging (LIDAR) mapping systems require multi-channel receivers with high sensitivity and bandwidth operating in the 1-1.5 µm wavelengths. One of the ways to improve the system performance is to improve the sensitivity of photo receiver performance. InGaAs avalanche photodiode (APD) sensor technology is considered for this wavelength region because of high reliability. However, commercially available InGaAs APDs have low sensitivity due to the high excess-noise InP material. Spectrolab has been developing low excess noise InGaAs avalanche photodiodes (APDs) with impact ionization engineering (I2E) structures and recently, APDs with excess noise factor of 0.15 was demonstrated using I2E APD devices. Single channel photo receivers built using low noise I2E APDs show an NEP of 150 fW/rt(Hz) over a bandwidth of 1 GHz, a record for InGaAs based APDs.

In this paper, we will report the progress on a 16 channel fiber coupled low noise photo receiver designed and built for a NASA program. The incident light is coupled into fibers through a telescope. The light then focused on the APDs through a pair of aspheric lenses. The details of the assembly and characterization of the photo receiver will be presented at the meeting.

8353-77, Session 13

Advances in ladar components and subsystems at Raytheon

M. D. Jack, Raytheon Co. (United States)

No abstract available

8353-78, Session 13

Small pixel pitch APD solutions for active and passive imaging

Y. Reibel, A. Kerlain, G. Bonnouvrier, D. Billon-Lanfrey, SOFRADIR (France); J. Rothman, L. R. Mollard, E. De Borniol, G. L. Destefanis, CEA-LETI (France)

There is a growing interest at reducing the size, weight, power and cost of military systems which often have to contain a large number of thermal and visible electrooptic functions in one camera. In the meantime, Active systems, using a near-infrared pulse laser and a fast, gated detector, are now regarded as potential candidates for application requiring performances beyond ranges usually achieved with thermal imaging.

This paper describes three recent developments using DEFIR MCT e-APD technology that address these needs. The first is a 15µm pixel pitch detector that can be switched to operate as a passive thermal imager, a laser-gated imager or a solar flux imager. A second development concerns an ultra-sensitive dual 2D/3D detector providing range information in a dynamic environment. Finally, an ultra high speed solution with a very low floor noise has been set up for applications with fast moving targets, Astronomy or Medical instrumentation.

MCT e-APD solutions with small pixel pitch opens a wide range of potential applications and contribute to bringing new generation EO sensor capability in a compact and lightweight payload configuration with extended performances. Perspectives and ongoing developments are discussed.

8353-79, Session 13

Development of low-excess noise SWIR APDs

X. Bai, P. Yuan, P. A. McDonald, J. C. Boisvert, J. J. Chang, R. Sudharsanan, Spectrolab, Inc., A Boeing Co. (United States)

There is a strong interest in developing sensitive Short Wavelength Infrared (SWIR) avalanche photodiodes (APDs) for applications like eye safe laser ranging and robotic vision. Excess noise associated with the avalanche process is critical in dictating the sensitivity of APDs. InGaAs APDs that are commonly used in the SWIR region have either InP or InAlAs as an avalanche layer and these materials have excess noise factor of 0.5 and 0.22 respectively. Earlier, Spectrolab had developed InGaAs APDs with impact ionization engineering (I2E) structures based on InAlAs and InGaAlAs heterostructures as avalanche layers. These I2E APDs showed an excess noise factor of 0.15 at a gain of 20. A photo receiver based on the I2E APD exhibited an NEP of 150 fW/rt(Hz) over 1 GHz bandwidth at 1.06 µm. Further reduction in excess noise and increased gain will improve the sensitivity of InGaAs APDs.

In this presentation, we will discuss our efforts to further reduce the excess noise (<0.15) in InGaAs SWIR APDs. A new multiplier structure based on InAlAs/InGaAlAs multiple quantum wells structures design is being developed to further improve the sensitivity of InGaAs APDs. Preliminary device characterization results show high optical gain over 100. Further characterization data including excess noise data will be presented at the meeting.

8353-80, Session 14

Mercury cadmium telluride (HgCdTe) passivation by advanced thin conformal Al2O3 films

R. Fu, J. Pattison, A. Chen, O. Nayfeh, U.S. Army Research Lab. (United States)

Mercury cadmium telluride (HgCdTe) is an important semiconductor for infrared (IR) imaging technologies due to a tunable bandgap that allows for detection from short-wave infrared (SWIR) to long-wave infrared (LWIR) wavelengths. Electrical passivation of the surface plays important role in reducing charge carrier recombination velocity. In order to reduce Hg depletion in HgCdTe, any passivation process must be performed at low temperature.

Atomic Layer Deposition (ALD) is an emerging deposition technology for thin highly conformal films to meet the demands of semiconductor technologies. Many ALD processes are optimized deposit films at an elevated temperature exceeding 200°C. Such deposition conditions are not suitable for deposition on HgCdTe. Therefore it is very desirable to develop an ALD process to enable the deposition at low temperature. The paper presented results for plasma assisted Al2O3 ALD on 4” silicon wafers using Cambridge Nanotech Fiji ALD system at temperature of 200°C, 80°C, 50°C, and 25°C. Trimethyl Aluminum (TMA) precursor and oxygen plasma was applied during the deposition. The Al2O3 films have been characterized by Woollam Spectroscopic Ellipsometer, Veeco Nanoman Atomic Force Microscopy (AFM), and four-point probe station.

Finally, room temperature plasma assisted ALD Al2O3 film’s passivation on HgCdTe has been studied. Conformal film was investigated through SEM images of the Al2O3 film deposited onto high aspect ratio features dry etched into HgCdTe. Minority carrier lifetime was measured and compared by photoconductive decay transients of HgCdTe before and after deposition. Room temperature ALD Al2O3 film increased the minority carrier lifetime of HgCdTe.

8353-81, Session 14

12µm pixel pitch development for 3-side buttable megapixel MW FPAs

P. Thorne, H. J. Weller, L. G. Hipwood, SELEX Galileo Infrared Ltd. (United Kingdom)

There is significant interest in small pixel pitch megapixel sized arrays and SELEX will present progress in our current 12um pixel pitch development programme.

Firstly, results will be presented from a 12um pixel pitch 256x256 element test array programme where arrays have been fabricated and bump bonded to a silicon ROIC. The arrays were fabricated using CMT grown by MOVPE on low cost GaAs substrates ideally suited to making very large arrays.

Secondly, SELEX will present progress on our 12um pixel pitch HD1920x1080p MW detector development programme. A summary of the technical challenges will be given along with an overview of the HD format array showing the 3-side buttable design approach and the formation of larger mosaic arrays. An overview of the ROIC will be given including the floor plan, details of the simple user interface, imaging modes and a summary of the device specification which targets

operation in excess of 30Hz frame rate and low power dissipation (<10mW). Devices are HOT compatible.

8353-82, Session 14

Status of MCT focal plane arrays in France

M. Vuillermet, D. Billon-Lanfrey, SOFRADIR (France); G. L. Destefanis, CEA-LETI (France)

This paper describes the recent developments of Mercury Cadmium Telluride (MCT) infrared technologies in France at Sofradir and CEA-LETI made in the frame of the common laboratory named DEFIR.

Among these developments, one can find the crystal growth of high quality and large Cadmium Zinc Telluride (CZT) substrates which is one of the fundamental keys for high quality and affordable detectors. These last years, a great effort was done on this topic and also on MCT epilayer process from Short Waves (SW) to Very Long Waves (VLW).

These developments about the quality of the material are needed for the challenge of the High Operating Temperature (HOT). Over these lasts years, the operating temperature of n/p MCT detectors was increase of several tens of Kelvin. In addition the development of the p/n MCT technology that reduces dark current by a factor ~100 saves about twenty Kelvin more. The next step for the increase in operating temperature will be the complex photodiodes architectures using molecular beam epilayer.

The reduction of the pixel pitches is another challenge for infrared technologies for Small Weight and Power (SWAP) detectors. Moreover, this reduction allows the increase in the resolution and consequently in the detection range of the systems.

In addition, last results on 3rd generation detectors such as multicolor focal plan arrays, 2D, 3D, low noise and high images rate focal plane array using Avalanche Photodiose (APD) are described.

8353-83, Session 14

State-of-the-art MCT IR-modules with enhanced long-term and cycle stability

R. Breiter, J. C. Wendler, H. Lutz, S. Rutzinger, T. Schallenberg, J. Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

Current trends on the enhancement of MCT FPA IR-modules are reduction of size, weight and power (SwaP), increase of resolution with large detector arrays, provision of starring LWIR or dual-band capability. This is achieved by reduction of pixel size, higher operating temperatures (HOT) or complex pixel structures together with the optimization of dewars, adapted cooling engines and proximity electronics.

To meet these demands AIM is working on MCT single-band MWIR or LWIR modules with formats 640x512 or 1280x1024 in 15µm pitch, a MWIR module 640x480 in 12µm pitch and a dual-band MWIR/LWIR module 640x512 in 20µm pitch. As a first step high operating temperature for MWIR 120K and LWIR 80K was demonstrated, development for MWIR >= 150K and LWIR >= 90K is ongoing. The modules are realized as integrated detector cooler assemblies (IDCA) with proximity electronics. The 640x512/15µm pitch modules are already available in application specific configurations e.g. having integral rotary or split linear cooling engines.

Besides implementation of the above mentioned capabilities also improvement in long term and cycle stability of IR-modules has been achieved which is important to fully benefit from increased mission times and longer maintenance periods by HOT. Especially starring MCT LWIR modules so far required sophisticated non-uniformity correction (NUC) processing to provide acceptable long term image quality while former scanning systems usually used implemented temperature references for NUC update. For a thermal imager setup with the LWIR 640x512/15µm module two-point correction with factory calibrated gain coefficients together with a new offset calibration after every cooldown cycle is used.

The paper will present the results of AIM's current starring single-band MCT IR-modules in MWIR or LWIR configuration especially regarding to their long term and cycle stability.

8353-84, Session 14

SWIR and NIR MCT arrays grown by MOVPE for astronomy applications

L. G. Hipwood, I. M. Baker, P. Abbott, N. Shorrocks, C. D. Maxey, SELEX Galileo Infrared Ltd. (United Kingdom); N. Bezawada, D. C. Atkinson, UK Astronomy Technology Ctr. (United Kingdom)

SELEX Galileo in collaboration with the Astronomy Technology Centre (ATC) undertook an activity to develop near infrared (NIR) and short wave (SWIR) sensor arrays as a precursor to a large format array in future phases of work. In this study, SELEX grew wafers of mercury cadmium telluride (MCT) material (cut off wavelengths ranging from 1.9µm to 2.7µm) using metal organic vapour phase epitaxy (MOVPE) on GaAs substrates. With substrate sizes up to 150mm available, this technology is ideal for very large arrays. Mesa structure arrays were processed and hybridised to multiplexers with a floating gate input.

MOVPE requires the growth of buffer layers which would absorb the shortest wavelengths. Results will be presented showing how the cut-on wavelength can be controlled by thinning these buffer layers and the subsequent achievement of a response to radiation shorter than 0.8 µm. Data will be presented showing sub 0.1 e/s/pix dark current at 80K, quantum efficiencies of 75% in H-band, and less than 3 minutes persistence after spot illumination into "double saturation".

APD structures designed for H and K band operation for use in wave-front sensing will also be described. These structures make use of an absorbing region with a graded cadmium mole fraction which is separate from the avalanche zone.

8353-85, Session 14

Very long wavelength infrared detection with p-on-n LPE HgCdTe

N. Baier, L. R. Mollard, O. Gravrand, G. L. Destefanis, G. Bourgeois, J. Zanatta, Commissariat à l'Énergie Atomique (France); P. Pidancier, SOFRADIR (France); L. Tauziède, Centre National d'Etudes Spatiales (France)

This paper presents recent development made at LETI Infrared Laboratory on the realization and characterization of planar p-on-n HgCdTe infrared photodiodes on very long-wavelength for space application. The HgCdTe active layer was grown by liquid-phase epitaxy (LPE) on lattice matched CdZnTe. The n-type HgCdTe base layer was obtained by indium doping. Planar p-on-n photodiodes were realized by Arsenic doping. Arsenic was selected as the candidate acceptor impurity since its activation is provided by post-implanted annealing in Hg vapour. Moreover, a good control and quality of electrical p-on-n junction are made possible due to low As diffusivity. As incorporation is achieved by ion implantation. Electro-optical characterizations on these p-on-n photodiodes were made on 384×288 FPAs with 25 µm pitch. The results show excellent current operabilities (99.85% at best) and very low dispersion, below 6%. The quantum efficiency is higher than 60% and remains constant on the whole detection spectrum. These photodetectors are background limited with a RMS noise to current shotnoise ratio lower than 1.05. Dark current is very low, with 59 nA for FPA at 78K, leading to a mean R0A product of 715 mΩ.cm², comparable to the state of the art, at cut-off wavelength of c = 15 µm. Gains with this p-on-n technology on n-on-p technology are discussed.

8353-115, Session 14

LWIR and VLWIR MCT technologies and detectors development at Sofradir for space applications

C. Leroy, P. Pidancier, P. Chorier, SOFRADIR (France); G. L. Destefanis, CEA-LETI (France)

For Sofradir, space applications have become a significant activity. As a consequence, Sofradir relies now on 20 years of experience in development and production of MCT infrared detectors of 2nd and 3rd generation for space applications. The panel of space applications in which Sofradir is involved is wide (earth observation, science, meteorology, civilian and military satellites,....) and covers a large spectrum ranging from visible up to VLWIR. The last developments for space applications have opened new requirements for LWIR and VLWIR infrared detectors with cut-off wavelength up to more than 15 µm. These requirements call for technology optimization in order to find the best trade-off between detector performances and operational constraints such as the highest possible operating temperature. In this paper, we present a review of the MCT technology optimization for LWIR and VLWIR applications. Then, a presentation of the different programs using these developments is made with a presentation of the associated results as they relate to performances and qualifications for space use.

8353-86, Session 15

Electrical characterisitcs of a MOVPE grown MWIR N+p(As)HgCdTe heterostructure photodiode build on a GaAs substrate

R. E. DeWames, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The N+p(As) hetero-structure architecture consists of a five layer structure , with the absorbing p (1015 cm-3) layer 3.3 µm thick sandwiched between two wider band gap p (As) and n (I) regions doped at 1016 cm-3. As shown in the figure a model has been developed that fits accurately the data reported1, see fig. 8, p.820. To explain the current density functional dependence on temperature, a donor flaw situated at 37.6 meV below the conduction band edge was assumed with the lowest hole and electron lifetimes τp0 and τn0 equal to 3.5*10-6 (s) and 10-10 (s) respectively. The p-side diffusion current equation is given by Jdiff-p side = (qNvdp/τp0)*exp (- Eflaw/ kT), where q is the elementary charge, Nv the valence band density of state, dp the thickness of the absorbing layer, and Eflaw(T) = Eg (T)- ∆Eflaw. Where, ∆Eflaw.= 37.6 meV and is taken to be a constant. It is conjectured that the donor state may be of origin in residual Hg vacancies in extrinsic As doped materials; donor states ~ 30 meV from the conduction band edge need to be assumed to explain the temperature behavior of n+- n-p (VHg) photodiodes . The noteworthy observation is that the diffusion current obeys the Arrhenius equation with the exponent Eflaw(T) which is < Eg (T); the ratio of G-R to diffusion is 0.2. The authors1 proposed that the radiative recombination mechanism was dominant for T ≥ 240K. This is not supported by our model that suggests SRH limited behavior all the way! As shown in the insert, Jdark= Jphoton at T=200K for F/1.4 optics and Tscene = 300K, spectral band (3-5 µm).

Dark Current Density Measured and Modeled as a Function of Inverse Temperature

8353-87, Session 15

State of MBE technology at AIM

J. Ziegler, J. Wenisch, D. Eich, H. Lutz, T. Schallenberg, R. Wollrab, AIM INFRAROT-MODULE GmbH (Germany)

As an alternative to the traditional liquid phase epitaxy (LPE) for HgCdTe (MCT) fabrication, molecular beam epitaxy (MBE) technology has generated a great amount of interest for well over two decades. MBE promises improved layer quality in terms of homogeneity, availability of large-area, inexpensive alternative substrates, and the possibility to fabricate 3rd generation infrared detectors. AIM has expanded into the field of MBE technology by installation of its own Veeco Gen20A MBE machine in 2009. In 2010, the system was upgraded to include a second growth module.

MCT growth on (211) GaAs substrates of 100 mm diameter has been developed and is now approaching production level readiness. MBE grown MWIR MCT wafers have been processed by AIM's standard planar technique. The detector chips were hybridized to the read out integrated circuit (ROIC) and processed up to a standard integrated detector cooler assembly (IDCA) with 640 x 512 pixels in a 15 µm pitch. Electro-optical performance shows a low and homogeneous NETD of 18.3 mK and a high operability of 99.31%.

To analyze the feasibility of MBE grown LWIR layers on GaAs, a MCT layer with 8.8 µm cut-off at 80 K has been fabricated and processed into 640 x 512 pixels, 15 µm pitch arrays. Initial characterization yielded promising results and illustrates the potential of MBE for LWIR MCT detector production.

This contribution will present the current state of MBE technology at AIM as well as latest electro-optical measurements on both MWIR and LWIR focal plane arrays.

8353-88, Session 15

High operating temperature mid-wavelength infrared HgCdTe photon trapping focal plane arrays

K. D. Smith, J. G. A. Wehner, A. M. Ramirez, E. P. Smith, Raytheon Co. (United States)

Raytheon Vision Systems (RVS) is developing HgCdTe 3D photon trapping or photonic crystal resonance structures for high operating temperature (HOT) broadband mid-wavelength (MWIR) infrared detection in the 0.5-5µm spectral range. The concept of using photonic crystals is relatively well understood and has been demonstrated for applications like VCSELs, which have a very similar device structure to a photovoltaic detector ; Krishna et al. have showed application of photonic crystals to infrared detectors. This paper will describe ongoing work at RVS related to realizing high performance, elevated operating temperature MWIR focal plane arrays (FPAs) with an approach that utilizes Molecular Beam Epitaxy (MBE) on Silicon growth of p-on-n HgCdTe detector designs, and deep dry-etching to form a photonic crystal that substantially reduces active detector and junction volume, and associated dark current, while also maintaining high quantum efficiency (QE).

In this paper results for the following will be reported: photonic crystal detector design, process improvements that enable photonic crystal detector and FPA fabrication, and both detector and 512 x 512 FPA results at elevated operating temperatures (200 K) that employ these novel detector design and process improvements. Figure 1 shows example photonic crystal detector simulations using Synopsys TCAD SDevice software upgraded with an EMW package that enables fully functional finite-difference-time-domain (FDTD) electromagnetic FEM simulation. Figure 2 shows dark current as a function of temperature for 30 µm unit-cell detectors with varying absorber volume, which compares a regular detector design with two photonic crystal detector designs. The feature of the photonic crystal designs is that dark current can be significantly reduced due to a reduction in detector absorber volume but without the loss of detector quantum efficiency (QE).

8353-89, Session 16

MWIR mercury cadmium telluride detectors for high operating temperatures

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Raising the operating temperature of MCT detectors has benefits in terms of reduced cooler power and increased life and enables an overall reduction in size and weight for handheld applications. The MCT composition can be tuned to achieve the required wavelength range at a given temperature. Work on detectors operating in the 3 - 5 μm atmospheric transmission window at operating temperatures up to 210K will be described. The influence of limiting factors such as excess noise, radiation shield emission, dark current and injection efficiency will be presented.

Packaging aspects will be discussed emphasising the importance of achieving low cost, weight and power for handheld applications.

Finally images will be presented showing performance from a higher operating temperature (HOT) camera.

8353-90, Session 16

HOT MWIR HgCdTe performance on CZT and alternative substrates

J. G. Pellegrino, R. E. DeWames, P. G. Maloney, C. Billman, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The HgCdTe ternary alloy with x ≈ 0.3 has internal quantum efficiency of 85% and at high operating temperatures (HOT) will be shown to be mostly radiatively limited. The purpose of this work is to examine the nature of dark currents in MWIR HgCdTe grown on lattice matched (CdZnTe) versus lattice mismatched substrates (GaAs and Si). A p+ /n device architecture was used for all samples. The MCT/CZT and MCT /Si have identical compositions (x=0.3021). The MCT/CZT shows a diffusion dominant behavior for temperatures down to 100K. At approximately 40K a deviation from thermal behavior is observed for MCT/CZT which is likely trap assisted tunneling. In contrast, G-R is observed for both MCT/Si and MCT/GaAs samples in the approximate temperature range of 100 - 150K. Beyond 150K the dark current behavior of MWIR HgCdTe is radiatively limited with little difference between the lattice matched and mismatched materials. The deviation of the other MCT/GaAs sample is due to a cadmium x-value composition difference (x=0.32 versus x= 0.30). An indicator of material - device quality is the temperature of the departure of diffusion dominant dark current to GR or a Trap Assisted Tunneling current.

We confirmed our results by comparing the dark current density versus temperature data for the MCT on Si (x=0.3021) sample with the dark current versus voltage data. Modeling the J dark versus temperature data for MCT on Si has yielded SRH lifetime parameters (ϒ =0.1, τinfinity = 2E-5 seconds) which concur with the dark current versus voltage data for a fixed temperature at 142K. The graph indicates that at 142K the dark current is most closely modeled by a GR dominant process for the reverse bias case.

8353-92, Session 16

High operating temperature InAs1-xSbx diode and bariode photodetectors

P. Klipstein, D. Aronov, E. Berkowicz, M. Brumer, A. Fraenkel, A. Glozman, S. Grossman, O. Klin, I. Lukomsky, O. Magen, I. Shtrichman, N. Snapi, M. Yassen, E. Weiss, SCD Semiconductor Devices (Israel)

In MWIR photodiodes made from InSb, InAs or their alloy InAs1-xSbx, the dark current is generally limited by Generation-Recombination (G-R) processes. In order to reach a background limited operating temperature higher than ~80 K, steps must be taken to suppress this G-R current. At SCD we have adopted two main strategies. The first is to reduce the concentration of G-R centres, by changing from an implanted InSb diode junction to a higher quality one grown by Molecular Beam Epitaxy (MBE). Our epi-InSb diodes have a background limited performance (BLIP) temperature of ~100 K at F/3, in 15 to 30 micron pitch Focal Plane Arrays (FPAs). This operation temperature increase delivers a typical saving in cooling power of ~20%. In order to achieve even higher operating temperatures, we have developed a new XBnn bariode technology, in which the bulk G-R current is totally suppressed. This technology includes nBnn and pBnn devices, as well as more complex structures. In all cases, the basic unit is an n-type AlSb1-yAsy / InAs1-xSbx barrier layer / photon-absorbing layer structure. These FPAs, with 15 to 30 micron pitch and a cut-off wavelength of ~ 4.1 micron, exhibit a BLIP temperature of ~160 K at F/3. The cooling power requirement is reduced by ~60% compared with conventional 77 K operation. The operation of both our diode and bariode detectors at high temperatures results in an improved range of solutions for various applications, especially where Size, Weight, and Power (SWaP) are critical. Advantages include faster cool-down time and mission readiness, longer mission times, and higher cooler reliability, as well as very low dark current and an enhanced Signal to Noise Ratio (SNR) at lower operating temperatures.

8353-93, Session 16

Photoconductive gain in barrier heterostructure infrared detectors

S. A. Myers, N. Gautam, E. Plis, Ctr. for High Technology Materials, Univ. of New Mexico (United States); C. P. Morath, V. M. Cowan, Air Force Research Lab. (United States); S. Krishna, Ctr. for High Technology Materials, Univ. of New Mexico (United States)

Infrared (IR) detector technologies with the ability to operate near room temperature are important for many applications including chemical identification, surveillance, defense and medical diagnostics. Reducing the need for cryogenics in a detector system can reduce cost, weight and power consumption; simplify the detection system design and allow for widespread usage. In recent years, infrared (IR) detectors based on unipolar barrier designs have gained interest for their ability to lower dark current and increase a detector's operating temperature.

Our group is currently investigating nBn and pBp detectors based on the InAs/GaSb strain layer superlattice (SLS) material system. Like the built-in barrier in a p-n junction, the heterojunction barrier blocks the majority carriers allowing free movement of photogenerated minority carriers. However, the barrier in an nBn or pBp detector, in contrast with a p-n junction depletion layer, does not contribute to generation-recombination (G-R) current due to the lack of a depletion region across the narrow band gap absorber material. Thus such detectors act as hybrids between photodiodes and photoconductors.

The mechanism of photoconductive (PC) gain has not been fully characterized in such device architectures and in many recent studies has been assumed to be unity. However, studies conducted with similar device structures have shown the presence of PC gain. In this report we will measure and analyze the impact of PC gain in detectors utilizing single unipolar barriers such as nBn and pBp detectors.

8353-94, Session 16

Numerical simulation of InAsSb/AlAsSb nBn detector arrays

J. Schuster, C. A. Keasler, Boston Univ. (United States); M. B. Reine, Consultant in Infrared Detectors (United States); E. Bellotti, Boston Univ. (United States)

The main goal of this work is to advance our three-dimensional numerical simulation model intended to study back-illuminated nBn detector arrays to encompass other relevant material systems. Due to the growing importance of this class of detectors, it is desirable to develop a physical simulation model that makes it possible to analyze the operation of back-illuminated nBn detector arrays and to optimize their performance. Numerical simulations are particularly important for back-illuminated small-pixel arrays because the absorber layer is not delineated and hence there is the possibility of significant crosstalk due to lateral diffusion. We have already studied the crosstalk in InAs/AlAsSb based nBn detectors. In this work, we expand our model to include InAsSb/AlAsSb-based detectors as well. InAsSb is a far more relevant material system since InAsSb with an antimony concentration of 9% is lattice matched to GaSb. This yields devices with a longer cutoff wavelength that can be fabricated on relatively cheap substrates. To develop the physical model we have first validated the material parameters for InAsSb and AlAsSb. Subsequently, we have used this data to perform the simulation of both 3x3, 5x5 and 7x7 back-illuminated nBn detector pixel arrays. The physical device model is based on the simultaneous solution of the carrier continuity and Poisson equations on a three-dimensional finite element grid that uses a classical beam-type generation model to describe the optical generation rate. Using our model we analyze the quantum efficiency and crosstalk as a function of the pixel dimension, device thickness and doping concentration.

8353-95, Session 16

320 x 256 complementary barrier infrared detector focal plane array for longwave infrared imaging

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A 320 x 256 Complementary Barrier Infrared (CBIRD) focal plane array for long-wavelength infrared (LWIR) imaging is reported. The arrays were grown by molecular beam expitaxy (MBE) with a 300 period 1.9 um thick absorber. The mean dark current density of 2.2 x 10^(-4) A/cm^(2) was measured at an operating bias of 128 mV with a long wavelength cutoff of 8.8 µm observed at 50% of the peak. The maximum quantum efficiency was 54% measured at 5.6 µm. Operating at T = 80K, the array yielded an 81% fill factor with 97% operability. Good imagery with a mean noise equivalent different temperature (NEDT) of 18.6 mK and a mean detectivity of D* = 1.3 x 10^(11) cm-Hz^(1/2)/W was achieved. The substrate was thinned using mechanical lapping and neither an AR coating nor a passivation layer was applied. This article provides the details of the fabrication process for achieving low-dark current LWIR CBIRD arrays. Discussion for an effective hard mask for excellent pattern transfer is given and appropriate mounting techniques for good thermal contact during the dry etching process is described. The challenges and differences between etching large 200 µm test diodes and small 27 µm FPA pixels are given.

8353-96, Session 16

High operating temperature midwave quantum dot barrier infrared detector (QD-BIRD)

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The nBn or XBn barrier infrared detector has the advantage of reduced dark current resulting from suppressed Shockley-Read-Hall (SRH) recombination and surface leakage. High performance detectors and focal plane arrays (FPAs) based on InAsSb absorber lattice matched to GaSb substrate, with a matching AlAsSb unipolar electron barrier, have been demonstrated. The band gap of lattice-matched InAsSb yields a detector cutoff wavelength of approximately 4.2 m when operating at ~150K. We report results on extending the cutoff wavelength of midwave barrier infrared detectors by incorporating self-assembled InSb quantum dots into the active area of the detector. Using this approach, we were able to extend the detector cutoff wavelength to ~6 m, allowing the coverage of the full midwave infrared (MWIR) transmission window. The high operating quantum dot barrier infrared detector (HOT QD-BIRD) shows infrared response at temperatures up to 225 K.

8353-97, Session 16

MWIR $InAs_{1-x}Sbx$ nCBn detectors data and analysis

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The AWARE Broadband program requires innovative photon trap detector architecture to achieve pioneering performance of MWIR detectors at 200 K. One of the ambitious requirements is to obtain high (> 80 %) quantum efficiency over the broad 0.5 m to 5.0 m spectral range Electromagnetic simulations show that using pyramids as photon trapping structures minimizes the reflection and maximizes absorption over the entire 0.5 m to 5.0 m spectral range. InAs1-xSbx as the absorber layer with a cutoff wavelength ~ 5.1 m at 200 K has been grown and photon trap compound barrier nCBn detectors have been fabricated and characterized. QE is high across the entire 2.0 m to 4.6 m band demonstrating the efficacy of the pyramids as photon trap structures and as a replacement for multi-layer AR-coatings. Measurements still need to be made in the visible wavelength region.

Material electronic structures for InAs1-xSbx were computed with a k p formalism. The zone-center states are calculated in Fourier space using a 14-band basis. Need for a 14-band basis rather than the common 8-band basis arises because of the sensitivity of the optical and electronic properties to the electronic structure in the secondary regions of the band structure. Conduction and valence bands through the nCBn detector at Vd = -0.2 and -1.4 V bias were calculated. There is a valence band barrier at Vd = -0.2 V. Effects of the valence band barrier are observed in the activation energy extracted from dark I-V vs temperature measurements. At Vd = -1.4 V, the activation energy is Ea = 278.9 meV which is near the bandgap energy Eg(x = 0.19, T = 0K) = 269.8 meV. At Vd = -0.2 V, the activation energy is Ea = 331.9 meV which is approximately equal to the bandgap energy plus the valence band offset. The detectors are dominated by diffusion current in the -1.4 V range and by the valence band offset at low bias values.

A 1024 x 1024 ROIC on an 18 m pitch is being designed to interface with the nCBn detector arrays presently being fabricated. 1024 x 1024 FPA data may not be available in time to traverse the approval cycle. However, ROIC features and test detectors data and analysis from the 1024 x 1024 detector array lots will be presented. In addition, results of band structure calculations, and analysis of I-V curves will be presented.

8353-98, Session 16

Improved IR detectors to swap heavy systems for SWaP

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Cooled IR technologies are challenged for answering new system needs like the compactness and the reduction of cryo-power which is a key feature for the SWaP (Size, Weight and Power) requirements.

Over the last years, Sofradir has improved its HgCdTe technology, with effect on dark current reduction, that opens the way for High Operating Temperature (HOT) systems that can get rid of the 80K temperature constraint, and therefore releases the Stirling cooler engine power consumption.

A compact 640×512 15µm pitch MW detector presenting high EO performance above 150K with cut-off wavelength above 5.0µm has been developed. Its different performances with respect to the market requirements for SWaP will be discussed.

High performance compact systems will make no compromise on detector resolution. The pixel pitch reduction is the answer for resolution enhancement with size reduction. We will therefore also discuss the ongoing development and results on small pitch detector for SWaP systems

8353-22, Poster Session

Multispectral detection of small vessels in infrared

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The paper deals with the problem of the detection of small vessels in harbor and naval base areas. The detection is the final result of a searching process. In infrared spectral range the searching is closely related to the monitoring and analysis of radiance from background. In case of maritime conditions it is connected, apart of the object itself, with mostly two environment types: air and water. The detection process is determined by a number of factors, such as parameters of the detection device, radiant properties of the surrounding environment and atmospheric transmission. Resulting analyses and simulations were preceded by experimental measurements conducted in real maritime environment. The measurements were performed by means of measurement-class infrared devices operating in the ranges covering nearly all usable infrared spectrum: NIR, MWIR, and LWIR . The experiment concept was described. Recorded radiometric and image data were analyzed and discussed. On the basis of measurements and recorded data the effective thermal contrast was determined between the tested object and surrounding environment. The results were then used for calculations of theoretical detection ranges in the infrared spectral bands. The detection ranges were calculated using NVTherm software. Sample results of research and analysis were presented in all three infrared spectral bands and compared with each other. In comparison to detection in single spectral band, multispectral detection process provides additional information which can be utilized during development and optimization of infrared detection devices. As a result it allows to increase effectiveness of the detection of small size objects in the maritime environment.

8353-110, Poster Session

Thermoelectric sensors for analytical measurement applications

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At the Institute of Photonic Technology (IPHT) thermoelectric sensors are developed, which are based on n-bismuth(87%)-antimony(13%) / p-antimony thermocouples. The sensors are designed as miniaturized multi-junction thermopiles made by thin-film and other microsystem technologies on silicon wafers. Their optimized thermal design in combination with the use of highly efficient thermoelectric materials allows achieving detectivities in the range of 10^8 up to 2x10^9 Jones. The sensor area is coated with an absorbing layer, which is alternatively an interference multilayer system or a metallic smoke. In the latter case the thermopile's broad and flat spectral response from UV to FIR is limited only by the transmission characteristics of the window material selected. The sensors are hermetically sealed under vacuum or an inert gas atmosphere.

In the past years a whole family of different thermal radiation sensors and sensor arrays up to 256 sensor channels was fabricated and tested under harsh conditions. With the high responsitivity and the linearity of the spectral response over a broad IR band as well as the rugged construction the outstanding performance of the sensor concept was demonstrated. Some of the sensors were qualified for space missions and will be deployed in several NASA and ESA projects as REMS, ROSETTA and BEPI COLOMBO.

8353-117, Poster Session

Passivation effect on the noise characteristics of midwave infrared InAs/GaSb superlattice photodiodes

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The quality of a photo-detector is limited by intrinsic dark noise current, therefor intentional passivation is necessary to decrease this noise current. In this work, we study the noise characteristic of a Mid-Wavelenght Infrared (MWIR) Indium Arsenide and Gallium Antimonide (InAs/GaSb) based superlattice (SL) photodiode devices with a designed structure of 60-periods n-type/ 60-periods non-doped i active region/90-periods p-type which were realized by molecular beam epitaxy (MBE) on a (001) p-GaSb substrate and passivated with an intential passivant of SiNx and SiOx as well as without intentional surface passivation. For the unpassivated and SiNx passivated samples, our noise measurements exhibit a frequency dependent as so call 1/f noise behaviour. In contrast, the SiOx passivated sample shows frequency independent plateau (i.e. ,,white"- part at low frequency region) and a reduction of the dark noise current by up to one order of magnitude at around 30 Hz. frequency regime which is attributed to the effective suppression of surface leakage currents and Shottky-limited behaviour up to Vbias = -0.2 V, where the peak responsivity was 1.4 A/W, the cut-off wavelength was 4.9 micrometer and the specific detectivity reached to 1.12X10^12 Jones. Moreover, it was found that for higher reverse bias (below -0.2 V at the ~30Hz), the classical Shottky-noise calculation does not satify to describe the noise mechanism in SiOx passivated SL, which shows a discrepancy factor of ~3 between theoritical calculated and experimental measured noise.

8353-118, Poster Session

Panoramic optical threat warning sensor

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A prototype panoramic threat warning sensor capable of addressing 360° of azimuth and from -10 to +30° from the horizon is undergoing development. It is intended to act as a cueing system for future active defensive systems, and is based on inexpensive optical technologies. These sensors are undergoing testing to demonstrate their viability to discern battlefield threats from solar clutter. It employs a novel solar blinding method that enhances a munition's flash against the background. Light, passing through the optic, simultaneously illuminates two sensor types. One of these, a focal plane array (FPA), reacts to further-out threats and determines their line of bearing. The other is a quadrant detector (QD) that detects close-in threats, giving their rough angle of attack and can cue appropriate defensive systems. The half-scale proof of concept prototype (Mk I) has been tested with both detectors. Its FPA response featured an excellent signal to clutter ratio. Tests are underway of a second generation full-scale prototype (Mk II) equipped with a similar FPA and have thus far provided results even more promising. Both the Mk I and MKII prototypes have also been mated to QDs and performed well in preliminary bench level optical testing. A key corollary to this work is the development of an apparatus for obtaining an absolute calibration of the above optical equipment. These calibrations will allow us to infer the threat warner's response to any threat whose radiance characteristics are known.

8353-119, Poster Session

Studies on a novel mask technique to depress side-wall processing damage of ICP-etched HgCdTe trenches

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It is well known that high aspect ratio trenches or holes are essential to realize high performance Hg1-xCdxTe infrared (IR) detectors. CH4-H2 based plasma dry etching has been widely investigated for this kind of application. Several groups have reported the impact of the high-density ‘’dry” electron cyclotron resonance (ECR) plasma or inductively coupled plasma ICP enhanced reactive ion etching (RIE) processes on HgCdTe epitaxial properties. For most of the reported studies and device fabrications, patterned thick photoresist (PR) films formed using a standard photolithography process were employed as a mask to etch HgCdTe material. Recently, the patterned silicon dioxide films as a mask had been implemented in our lab to improve the smoothness and cleanliness of HgCdTe ICP etched surface, and also to increase the etching selectivity between HgCdTe and the mask films. However, we found that the side-wall processing damage of ICP etched trenches was increased obviously when the mask pattern films were thinned considering the high etching selectivity and the limited thickness of silicon dioxide mask film.

As a novel mask technique, the improved mask patterns are capable to maintain the high etching selectivity and reduce the side-wall ion-physical bombardment of ICP etched HgCdTe trenches simultaneously by integrating the patterned high-etch-selectivity silicon dioxide films on the surface of the high-aspect-ratio thick PR patterns. Current-voltage curves of the prototype device show that the novel mask technique is readily available and promising for HgCdTe etching.

8353-121, Poster Session

Study on optimizing the thickness of silicon window of WLP for IR sensor

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Silicon is a promising material as a window platform for packaging MEMS(microelectromechanical systems), especially, IR(Infrared Ray) sensors with WLP(wafer level package), because silicon has advantages in price and CMOS process compatibility compared to Ge window although Ge exhibit higher IR transmittance than Si. This paper report optimized thickness for Si window in the range of 8 ~ 12 um, LW-IR(Longwave IR). Two of important things which have to be considered in window material of IR sensor are minimizing absorption of IR and minimizing deformation by difference of pressures between outside and inside of the package.

Because of tradeoff between minimizing absorption and minimizing deformation, optimization of thickness is important. Infrared absorptance of silicon was measured as varying thickness from 700 um to 100 um of the Si window. Decreasing the thickness of silicon made the absorption smaller. Under 300 um, the difference of absorptance with decreasing thickness are as small as negligible. Degree of deformation according to varying thickness of the Si window was calculated by simulation as functions of pressure differences, and package area.

In both results, we can suggest optimized thickness of silicon window for WLP of LW-IR sensor.

8353-122, Poster Session

SWIR imaging for facial image capture through tinted materials

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The use of Short-Wave Infrared (SWIR) imaging (0.7-2.5 microns) and illumination technology is at the forefront of system development for both day- and night-time operational scenarios for military and law enforcement. Along with enabling night-time operations, a secondary benefit of SWIR imaging is that it offers the possibility to capture images through tinted materials, such as tinted architectural, automotive glass or sunglass lenses. The use of SWIR technology introduces challenges to facial recognition (FR) when comparing cross-spectrally from a visible gallery to images captured in the SWIR band [1, 2]. The challenges of SWIR FR are further compounded by the presence of tinted materials in the imaging path due to varying material types, lighting conditions, and viewing angle. The paper discusses material and optical characterization efforts undertaken to understand the effects of temperature, interior and exterior light sources, and viewing angle on the quality of facial images captured through tinted materials. Temperature vs. spectrum curves are shown for tinted architectural, automotive and sunglass materials over the range of -10 to 55C. The results of eye detection under various permutations of interior and exterior lighting along with viewing angle are used to evaluate the efficacy of cross-spectral FR under these conditions, and identify challenge areas requiring further study.

[1] T. Bourlai et al., “Cross-spectral Face Verification in the Short Wave Infrared (SWIR) Band”, ICPR, 2010.

[2] N. Kalka et al., “Cross-spectral Face Recognition in Heterogeneous Environments: A Case Study on Matching Visible to Short-wave Infrared Imagery”, IJCB, 2011.

8353-123, Poster Session

Electrical characterization of (GaIn)Sb/InAs T2SLS detector materials using CV, hall effect, and capacitance transient measurements

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We have applied the capacitance transient spectroscopy technique as a diagnostic tool for understanding deep level traps in type II strain layer superlattice (T2SLS) materials used for LWIR FPAs. Our objective is to develop relationships between MBE growth process parameters and the density and nature of deep level traps within the material. A better understanding of these relationships will help drive MBE growth improvements towards detector devices with reduced dark currents, improved quantum efficiencies, and hence, higher performance FPAs. The capacitance transient (CT) technique extracts information about the traps within the depletion region of the one-sided p-n junction located between the photodiode’s absorbing region and contact layer by measuring the capacitance response following a trap-filling voltage pulse applied to the diode. Following the voltage pulse, the junction capacitance experiences an initial offset with an algebraic sign determined by the trapped carrier type (minority or majority), and with a magnitude proportional to the density of traps, followed by a decay to its steady state value dictated by the trap emission rate. The trap activation energy is determined from the temperature-dependent emission rates extracted from CT measurements made over a range of temperatures. From 78K capacitance-voltage (CV) measurements, we determined the background doping concentration to be 8E14 cm-3 in our best-performing T2SLS material. CT measurements made on the same MBE material revealed the presences of both minority and majority carrier traps. Trap density and activation energy results from measurements made on several T2SLS structures will be presented along with details of the analysis.

8353-125, Poster Session

Infrared detection module for optoelectronic sensors

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The paper presents the construction and test results of new detection module. This module is dedicated to NOx optoelectronic sensors operates basing on Cavity Enhanced Absorption Spectroscopy technique. In this module Polish detector manufactured at the VIGO System Ltd. company is applied. The infrared detector is integrated with transimpedance preamplifier. High sensitivity of detection module was achieved by both matching the IR detector to the preamp and minimizing noises. High sensitivity of the detector was achieved by using photodiodes with immersion lens. Immersion lens enables optimization of the detector area, decreasing detector capacity and time constant. Detector noise was reduced as a result of photodiode cooling by means of a thermoelectric cooler and reverse biasing. TEC controller stabilizes detector temperature, with high precision, in wide ambient temperature range.The noise level and the available preamplifier bandwidth depend on the capacity of a photodiode. The capacity of the photodiode can be achieved by using an immersion lens and reverse biasing. The preamplifier provides an option of DC supply of reverse bias voltage to the detector, which constitutes the prerequisite for obtaining maximum signal-to-noise ratio in a broad frequency band.

8353-126, Poster Session

Initial testing of a Si:As blocked-impurity-band (BIB) trap detector

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We discuss the design, construction, and initial test results of a Si:As blocked-impurity-band (BIB) trap detector. The trap consists of two rectangular BIB devices configured in a v-shaped geometry. This trapping geometry is designed to yield a minimum of 7 bounces before exit for incident light within an f/4 cone with 3 mm clear aperture. The individual BIB devices consist of 70 µm thick active layers with As doping near 1.7x10^18 cm^-3, and have dark currents of approximately 100 nA at an operating temperature of 9 K. A simple ray-tracing model of the trap based on the measured absorptance of the detector elements predicts an external quantum efficiency of > 0.95 over the 4 to 28 micrometer spectral range and significant suppression of the etalon fringes present in the spectral responsivity of a single element. We have made initial responsivity measurements of the trap compared to a calibrated 5 mm diameter pyroelectric detector over the 4 to 16 micrometer spectral range using the fiber-coupled output of a Fourier-transform spectrometer. We also discuss the results of initial comparison measurements of the trap detector to an absolute cryogenic radiometer viewing the output of a calibrated blackbody source at discrete filter bands from 3 to 13 micrometers. This new trap detector has the potential to provide the infrared community with a high quantum efficiency, spectrally flat standard detector over the 4 to 28 micrometer wavelength range.

8353-127, Poster Session

Commercially developed, mixed-signal CMOS process features for advanced ROICs and image sensor products in 0.18µm technology node

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Increasingly complex specifications for next-generation focal plane arrays (FPAs) require smaller pixels, larger array sizes, low power consumption and reduced costs. We have previously reported on the commercially available 0.5um to 0.18um mixed CMOS technology nodes with high-density 4fF/um^2 linear MIM capacitors, multiple resistors (poly, nwell), up to 40V LDMOS FETs, NPNs, PNPs and various design enablement features. In this paper, we will report results on new features in the 0.18um technology platform. First, we will present details on the characterization and modeling of reduced 1/f noise FETs with at least 4X noise reduction over existing devices. Second, we will report on the characterization of compact footprint low-threshold nFETs and pFETs for use in small pixels. Third, we will discuss high-density capacitance solutions required in small pitch pixels obtained by increased levels of stacking. Accurate modeling of small area capacitances will also be presented. Next, non-volatile memory options such as 5V programmable e-fuses and gate oxide anti-fuse options available in our commercial CMOS process offerings will be described. Applications of these devices for next generation read out integrated circuits (ROICs) for cooled and uncooled FPAs and in visible image sensor processes in development at TowerJazz, Newport Beach will also be discussed.

8353-128, Poster Session

The estimation of thermal conductance values of µ-bolometers in a FPA with some selected structures and pitches

S. Park, S. Han, C. S. Han, Hoseo Univ. (Korea, Republic of); H. C. Lee, KAIST (Korea, Republic of)

In this paper, the extreme thermal conductance values of µ-bolometers with selected structures are estimated. The steady-state temperature of a µ-bolometer for a given heat source is determined by its thermal conductance. In order to achieve a well-controlled bias cancellation, the two extreme thermal conductance values are required for an active and a reference bolometer in a µ-bolometer FPA. We study the thermal properties and estimate the thermal conductance values of µ-bolometers with selected structures having 17, 25 µm pitch. Thermal characteristic study is carried out with two methods, analytical calculations and FEM analyses on the device models of the selected structures. From the results of this study, the thermal conductance value of a one-turn-leg structure having 17 µm pitch is in the range of 10-7 to 10-5 W/K, while that having 25 µm pitch is 10-8 to 10-4 W/K. We will present the details of our study.

8353-129, Poster Session

Design and realization of 144 x 7 TDI ROIC with hybrid integrated test structure

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Design and realization of a 144x7 silicon readout integrated circuit (ROIC) based on switched capacitor TDI for MCT LWIR scanning type focal plane arrays (FPAs) and its corresponding hybrid integrated test circuits are presented. TDI operation with 7 detectors improves the SNR of the system by a factor of $\sqrt{7}$, while oversampling rate of 3 improves

the spatial resolution of the system. ROIC supports bidirectional scan, 5 adjustable gain settings, bypass operation, automatic gain adjustment in case of mulfunctioning pixels and pixel select/deselect properties. Integration time of the system can be determined by the help of an external clock. Programming of ROIC can be done in parallel or serial mode according to the needs of the system. All properties except pixel select/deselect property can be performed in parallel mode, while pixel select/deselect property can be performed only in serial mode. ROIC can handle up to 3.75V dynamic range with a load of 25pF and output settling time of 80ns. Input referred noise of the ROIC is less than 750 rms electrons, while the power consumption is less than 100mW. To test ROIC in absence of detector array, a process and temperature compensated current reference array, which supplies uniform input current in range of 1-50nA to ROIC, is designed and measured both in room and cryogenic (77°K) temperatures. Standard deviations of current reference arrays are measured 3.26% for 1nA and 0.99% for 50nA. ROIC and current reference array are fabricated seperately, and then flip-chip bonded for the test of the system. Flip-chip bonded system including ROIC and current reference test array is successfully measured both in room and cryogenic temperatures, and measurement results are presented. The manufacturing technology is 0.35μm, double poly-Si, four metal, 5V CMOS process.

8353-130, Poster Session

Adaptive bias voltage technique of IRFPA

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IRFPA (infrared focal plane array) usually has a certain response dynamic range and can be set by its own bias voltage. But, most of the thermal imagers do not make use of the characteristic of the IRFPA. The bias voltage is usually fixed when the thermal imager works. This approach dose not fully plays the role of the IRFPA. The temperature of infrared scene is constantly changing and if the response dynamic range is set to a fixed value, two situations may occur. One is that the dynamic range of the scene is far bigger than IRFPA, and then the response of IRFPA is not the real scene gray. The response of IRFPA at some scene temperature may be cut off. The other is that the dynamic range of the scene is far smaller than IRFPA, and then most response dynamic range is wasted which reduces the ability of distinguishing details. In order to solve this problem, we brought out the adaptive bias voltage technique of IRFPA in this paper. We computed the scene real temperature range according to the response of IRFPA and current bias voltage, set the adjusting threshold of bias voltage and computed the match bias voltage. We adopt the technique in order to guarantee that the response dynamic range is accordant with the real scene continuously. The theory derivation and experiment demonstrate that the technique is effective in making the scene temperature dynamic rang and response dynamic range of IRFPA be consistent. This technique can increase the IR image detai1 resolution by a big margin.

8353-131, Poster Session

Parylene supported 20μm*20μm uncooled thermoelectric infrared detector with high fill factor

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Described is an uncooled surface-micromachined thermoelectric(TE) infrared detector that features P-doped polysilicon/Nichrome(Cr20-Ni80) as the thermocouple material pair embedded in Parylene-N, which isolates the hot junction from the substrate.

Parylene-N is a polymer with a very low thermal conductivity of ~0.1W/m.K that can be deposited at room temperature. In addition, it is resistant to common etchants and can be easily patterned in O2 plasma.

Simulation shows that the thermal conduction from the hot junction to the substrate through the TE wires is dominant (G_TE G_parylene). So, by further reducing the size of the TE wires, G_TE could be decreased and hence, responsivity could be improved while parylene can provide the mechanical strength for the thin TE wires.

This detector features an umbrella-like absorber that permits high fill factors. The device area is 20um*20um and the absorber area is about 19um*19um leading to a fill factor of as high as 90%. The absorber is an optical cavity composed of a three-layer stack NiCr/SiN/NiCr.

At room temperature, the responsivity of 100V/W @5Hz and the response time of not greater than 26ms were measured in vacuum when viewing a 500K blackbody with no concentrating optics. The dominant source of noise in thermoelectric IR detectors is typically Johnson noise when the detectors are operating in an open circuit condition. The fabricated detectors have resistances from 50 to 60KOhm which results in Johnson noise of about 32nV/Hz^0.5. However, due to ambient noise (e.g. pump vibrations, measurement setup, etc.) the measured noise at 5Hz is about 68nV/Hz^0.5. The D* is calculated to be 2.9x10^6cmHz^0.5/W.

8353-132, Poster Session

Update on Tinsley Visible Guality (VQ) aluminum optics

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Recent advancement has been made in producing difficult aspheric mirrors in bare aluminum to visible imaging quality. Polished bare aluminum mirrors offer significant producability and cost advantages for defense and surveillance systems, and can satisfy the environmental and performance needs of many systems. Comparisons will be made to recent developments in the finish on Electroless Nickel. We describe the finish of both bare VQ Al and electroless nickel (EN) clad mirrors in terms of power spectral density levels that can now be routinely achieved. Parameters are provided to guide the designer in specifying VQ mirrors, and in considering trades with other materials.

8353-133, Poster Session

Manufacturing status of Tinsley Visible Quality (VQ) bare aluminum, and an example of snap together assembly

K. G. Carrigan, L-3 Integrated Optical Systems (United States)

For two decades, simultaneous single point diamond turning of aluminum mirrors and their mounts has deterministically reduced the degrees of freedom in subsequent alignment. This has several advantages, principally cost and time of assembly being significantly reduced. This savings is even more apparent when difficult to align off-axis systems are required. Previously, surface errors from diamond turning have limited the snap-together alignment advantage to systems that operate in the infrared. We will describe methods that permit post-polishing the mirror to visible imaging quality, yet retaining the relationship between precision machined mount and mirror surface to the extent that visible imaging requirements can be met for the system with snap together assembly. A recent example will be discussed.

8353-134, Poster Session

Precise optomechanical characterization of assembled IR optics

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The imaging quality of assembled IR-Optics is strongly influenced by the alignment errors of the single optical elements (lenses) with respect to each other.

In this contribution we present a measurement system for the high-precision full optomechanical characterization in assembled systems. One main component of the measurement device is a IR-optimized electronic autocollimator that enables the determination of the position of each center of curvature with respect to a given reference axis. The obtained measurement data are further processed in order to provide the shift and tilt of an individual lens or group of lenses with respect to a defined reference axis.

With the help of a suitable adjusting facility the optical system under test is aligned to the axis of a low coherence interferometer system. This system, that is operation in the IR range as well, determines the position of the vertex positions along the optical axis.

Only the accurate alignment provided by the combination of the autocollimator-based centration testing and the low-coherent interferometer enables the determination of the air gaps between lenses and lens thicknesses with an accuracy below one micrometer.

In summary, the presented system allows the high-precision full optomechanical characterization even of surfaces inside of the optical assembly in a non-contact way without touching and destroying the sample.

8353-135, Poster Session

Evaluation of the effect of optical manufacturing tolerances on the performance of an infrared imager

A. Uçar, G. G. Artan, T. Karakas, TÜBITAK SAGE (Turkey)

Optical manufacturing tolerances are vital regarding the overall performance of optical devices. These tolerances have to be precisely calculated for the application-specific. In this sense, radius of curvature, thickness, angle between the surfaces, and conic constant for aspheric surfaces constitute the most significant parameters affecting the optical performance. In some cases, optical performance problems maybe encountered as insufficient calculation sharpness or inadequate manufacturing tolerances. In this study centering and thickness tolerances measured by three dimensional coordinate measurement system (micrometric scale), radius of curvatures and conic constants measured by interferometric system (nanometric scale). The relation between the tolerances of manufacturing parameters and optical performance is examined. Finally, a comparison of practical and theoretical tolerance effects on optical performance is conducted.

8353-138, Poster Session

Modeling of dark current suppression in unipolar barrier infrared detectors

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It is the expected to improve the performance of infrared detectors by increasing the photocurrent and reducing the dark current. But, only a small improvement can be realized by increasing photocurrent because the quantum efficiency of infrared detectors is already relative high. It is well known that suppression of dark current has a much larger influence on the performance of infrared detectors, as it can be reduced by several orders of magnitude. Most recent improvement in performance of infrared photodetrctors has been enabled by the application of band gap engineering to reduce dark currents. A unipolar device structure to suppression dark current has recently been proposed by Savich et al, using AlAs0.18Sb0.82 as an ideal barrier material in the InAs material system. AlAs0.18Sb0.82 exhibits a zero valence band offset with respect to InAs and possesses a large barrier in the conduction band.

In this paper, the physical mechanism of different barrier structures is elaborated. To better understand the performance characteristics of the devices and optimize the structures, we have performed numerical drift-diffusion simulations of both n-side and p-side InAs based unipolar barrier photodiodes with AlAs0.18Sb0.82 barriers, n-barrier-n (nBn) structure detectors, as well as conventional pn junction detectors. The dark and photo current of different device structures have been investigated. Comparing to conventional devices, the unipolar barrier device has shown significant performance improvement.

8353-144, Poster Session

The first fabricated dual-band uncooled infrared microbolometer detector with a tunable micro-mirror structure

S. Keskin, T. Akin, Middle East Technical Univ. (Turkey)

This paper presents the first fabricated dual-band uncooled resistive infrared thermal microbolometer, which is implemented with a resistive microbolometer and a tunable micro-mirror structure. The tunable reflective micro-mirror is suspended underneath the suspended resistive microbolometers having a 35 µm pixel pitch, and they are switched between two positions by the application of an electrostatic voltage for obtaining different responses in two wavelength windows, namely the 3 5 µm and 8 14 µm, by tuning the optical tunable resonant cavity. This approach allows to assess the actual temperature of the viewed scene by comparing the responses of the detector in these two wavelength windows. The absorption coefficients of the detector are simulated by using the cascaded transmission line model, and the sacrificial layer thicknesses are optimized to obtain maximum absorption from these two wavelength regions. The absorption coefficients obtained from the measurements are in accordance with the simulations. The responsivity measurements results shows that the absorption is decreased in an amount of 17.9 % in the 3-5 µm spectral band, while the absorption is increased in an amount of 8.5 % in the 8 14 µm spectral band, depending on the micro-mirror position. These initial results are promising for the dual-band detection using uncooled infrared microbolometer detectors.

8353-145, Poster Session

An analysis for the absorption enhancement using plasmonic structures on uncooled infrared detector pixels

S. Z. Lulec, S. E. Kucuk, Middle East Technical Univ. (Turkey); E. Battal, A. K. Okyay, Bilkent Univ. (Turkey); Y. Tanrikulu, T. Akin, Middle East Technical Univ. (Turkey)

This paper introduces an analysis on the absorption enhancement in uncooled infrared pixels using plasmonic structures. Different plasmonic structures are designed and simulated on a stack of layers, namely gold, polyimide, and silicon nitride in order to observe the effect of these structures on different wavelength ranges. The simulated structures are fabricated and the reflectance measurement is conducted using an FTIR ellipsometer. The results show that the effect of the plasmonic structures on the reflection spectrum in the 8-12 µm wavelength region has similar trends both in simulated and measured data. Moreover, the plasmonic structures are simulated on different microbolometer pixels for absorption enhancement. The best result obtained in these simulations gives an absorption enhancement of 16% in the 8-12 um band, resulting in a total absorption percentage of 80%.

8353-137, Poster Session

Laser power and temperature dependence on laser beam induced current signal in As-doped p-type HgCdTe

Y. Chen, W. Hu, X. Chen, Z. Ye, Shanghai Institute of Technical

Physics (China); J. Wang, Univ. of Science and Technology of China (China); C. Lin, X. Hu, W. Lu, Shanghai Institute of Technical Physics (China)

Laser beam induced current (LBIC) is a high-resolution and non-destructive optical characterization technique which has been proved useful in qualitatively assessing electrically active defects and localized nonuniformities in HgCdTe materials and devices. However, the analysis of LBIC measurements has been considered to be a difficult task because of the large number of parameters influencing the LBIC signal.

This work describes specific experimental conditions under which the shape of the LBIC signal, as well as the polarity and magnitude, is greatly affected by the temperature and laser beam power. The polarity inversion of laser beam induced current (LBIC) signal at low temperature and irradiance in As-doped p-type HgCdTe is investigated in this paper. The experiment results show that the peak magnitude of the LBIC signal profile at 260 K decreases with decreasing temperature and ultimately tends to be zero at 180 K. A new peak LBIC signal emerges as the laser power drops to 2.5×104W/cm2 at 180 K. It is also noted that the peak-to-peak width of the LBIC signal increases when the temperature decreases. Considering the mechanism of LBIC signal and the surface properties of the diode, a photocarrier spreading mechanism is developed to demonstrate the reverse of the LBIC signal.

8353-143, Poster Session

MWIR and LWIR photodetectors made of InAs/InAsSb Type-II superlattices

O. O. Cellek, H. S. Kim, E. H. Steenbergen, H. Li, Z. Lin, S. Liu, Y. Zhang, Arizona State Univ. (United States)

Ga-free InAs/InAsSb type-II superlattice (T2SL) structures are suitable for both MWIR and LWIR photodetector applications. Recently the material system demonstrated minority carrier lifetime greater than 412 ns at 77 K, an order of magnitude longer than that of the conventional InAs/Ga(In)Sb T2SLs LWIR band. Longer carrier lifetime is required for low dark current and high operating temperature. This paper will report our latest results on the structural designs, materials growth, and fabrication of photodetectors made of MWIR and LWIR InAs/InAsSb type-II T2SL structures and their detailed characterization.

8353-147, Poster Session

MT6425CA: a 640 X 512-25µm CTIA ROIC for SWIR InGaAs detector arrays

S. Eminoglu, Y. U. Mahsereci, C. Altiner, T. Akin, Mikro-Tasarim (Turkey)

This paper reports the development of a new CTIA ROIC (MT6425CA) suitable for SWIR InGaAs detector arrays which has a format of 640 × 512 and pixel pitch of 25 µm and has been developed with the system-on-chip architecture in mind, where all the timing and biasing for this ROIC are generated on-chip without requiring any external inputs. MT6425CA is a highly configurable ROIC, where many of its features can be programmed through a 3 wire serial interface allowing on-the-fly configuration of many ROIC features. The ROIC runs on a 3.3 V supply voltage, and it uses a nominal 10 MHz clock. It performs snapshot operation both using Integrate-Then-Read (ITR) and Integrate-While-Read (IWR) modes. The CTIA type pixel input circuitry has a full-well-capacity (FWC) of about 320.000 e-, with an input referred noise of less than 110 e- at unity gain level at 300 K. MT6425CA has programmable number of outputs, where 4, 2, or 1 output can be selected along with an analog reference for pseudo-differential operation. The integration time can be programmed from 0.1 µs up to 1 s with steps of 0.1 µs. The gain and offset in the signal chain can be programmed to adjust the DC level and voltage swing at the output, which can be increased up to 3.0 V, i.e., close to supply rails. Power dissipation of this ROIC can be adjusted according to speed requirements, and by default the ROIC dissipates less than 130 mW from 3.3 V supply when used at full speed and widow size with 4 outputs. MT6425CA is fabricated using a modern mixed-signal CMOS process on 200 mm CMOS wafers with a high yield of 80 %, yielding more than 45 working parts per wafer. It has been silicon verified both at room and cryogenic temperatures, and tested parts are available either in wafer or die levels with test reports and wafer maps. A USB based compact camera electronics and imaging software is also available to help potential users of this ROIC to do quick evaluation of these new and upcoming ROIC products of Mikro-Tasarim Ltd.

8353-99, Session 17

Sub-monolayer InAs/InGaAs quantum dot infrared photodetectors

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Sub-monolayer quantum dots (SML-QDs) offer an alternative zero-dimensional system to the well studied Stranski Krastanov (SK) quantum dots. SML QDs consist of alternate submonolayer stacks of InAs/GaAs such that effective quantum confinement is achieved in the structure. Advantages of the SML-QDs include less strain energy, small base diameter, better three-dimensional quantum confinement, large dot density, tailorable aspect ratio, and absence of a wetting layer.
A quantum dot infrared photodetector based on the SML-QD (SML-QDIP) can improve device performance since the wetting layer does not contribute to normal-incidence absorption. We report on InAs/InGaAs SML-QDIP detector performance. The SML-QDIP samples were grown by molecular beam epitaxy (MBE) system. The structure consists of 2~6 stacks 0.3 ML InAs SML-QDs embedded in a 5.3 nm In0.15Ga0.85As quantum well (QW) surrounded by 1nm GaAs, 2nm Al0.22Ga0.78As confinement enhancing barrier, 48 nm thick Al0.07Ga0.93As barriers. At 300K, the SML-QDIP PL spectra show strong emission at 1.26~1.35eV. The spectral response peak occurs at 7.2~7.8 µm due to intersubband transition from SML-QDs ground state to InGaAs QW excited state. The peak detectivity and responsivity of the device with 4 stacks 0.3ML InAs layers was measured to be 4.0x109 cm.Hz1/2W-1 and 0.4 A/W respectively (77K, 0.6V, 7.5µm, f/2) at around 0.4V operating bias. Detailed study of device design, fabrication and characterizations for these SML-QDIP detectors will be presented.

8353-100, Session 17

Solution-processed colloidal quantum dot photodiodes for low-cost SWIR imaging

E. J. Klem, J. S. Lewis, C. Gregory, G. Cunningham, D. Temple, RTI International (United States)

While InGaAs-based focal plane arrays (FPAs) provide excellent detectivity and low noise for SWIR imaging applications, wider scale adoption of systems capable of working in this spectral range is limited by high costs, limited spectral response, and costly integration with Si readout integrated circuits (ROICs). RTI has demonstrated a novel photodiode technology based on IR-absorbing solution-processed PbS colloidal quantum dots (CQD) that can overcome these limitations of InGaAs FPAs. We have fabricated devices with quantum efficiencies exceeding 50%, and detectivities that are competitive with that of InGaAs. Dark currents of ~2 nA/cm2 were measured at temperatures compatible with solid state coolers. Additionally, processing these devices entirely at room temperature makes them compatible with monolithic integration onto ROICs, thereby removing any limitation on device size, enabling rapid scale-up, and significantly reducing cost. We will show early efforts towards demonstrating a direct integration of this sensor technology onto a Si ROIC and describe sensors sensitive from the ultraviolet to 1800 nm at a cost comparable to that of CMOS based devices. This combination of high performance, dramatic cost reduction, and multispectral sensitivity is ideally suited to expand the use of SWIR imaging in current applications, as well as to address applications which require a multispectral sensitivity not met by existing technologies.

8353-101, Session 17

Demonstration of high responsivity(~2.2 A/W) and detectivity(~10 11 Jones) in the long wavelength (~10.2µm) from InGaAs/GaAs quantum dot infrared photodetector with quaternary In0.21Al0.21Ga0.58As capping

S. Chakrabarti, S. Adhikary, Indian Institute of Technology Bombay (India); Y. Aytac, A. G. U. Perera, Georgia State Univ. (United States)

The Self-assembled InGaAs/GaAs quantum dot infrared detectors (QDIPs) have emerged as a promising technology in many applications such as missile tracking, night vision, medical diagnosis, environmental monitoring etc. On account of the 3-D confinement of carriers in QDs, a number of advantages arise over the QW counterparts. Here we report a quaternary (InAlGaAs) capped In(Ga)As/GaAs QDIP. The samples were grown on a semi-insulating (001) GaAs substrate by solid source molecular beam epitaxy (MBE), and the dots were then capped with a combination of 30Å quaternary ($In_{0.21}Al_{0.21}Ga_{0.58}As$) and 500Å of GaAs layer. Both the QD layer and the combination capping were repeated for 35 periods. The device was fabricated by conventional photolithography, ICP etching and metal evaporation technique. XTEM image of the sample depicted nice stacking of defect free quantum dot layers. The dark current is symmetric both for positive and negative bias with a low dark current density of 1.36×10^{-6}A/cm^2 at 77K and 6.92×10^{-4}A/cm^2 at 200K at a bias of 1V. The high intense peak response observed at 10.2µm, with a very narrow spectral width ($\Delta\lambda/\lambda$) of 0.14 ($\Delta\lambda$ is the FWHM) , is probably due to bound-to-bound transition of carriers in the QDs. A very high responsivity of 2.2 A/W was measured at a bias of -0.40 Volt bias. The highest value of detectivity is measured to be 1.01×10^{11} cm.Hz$^{1/2}$/W at a bias of 0.3V. On rapid thermal annealing the values of peak responsivity and detectivity are found to increase further. DST India is acknowledged.

8353-102, Session 17

QWIP infrared detector production line results

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Since 1997, Sofradir has been working with Thales & Research Technologies (TRT) to develop and produce Quantum Well Infrared Photodetectors (QWIP) as a complementary offer with Mercury Cadmium Telluride (MCT) Long Wave (LW) detectors, to provide large LW staring arrays.

Thanks to the low dark current technology developed by TRT, the QWIP detectors can be operated at FPA temperature above 73K, enabling the production of compact IR cameras thanks to the use of compact microcoolers. The TV/2 VEGA-LW detector (25µm pitch 384×288 IDDCA) is integrated in the Catherine-XP thermal imager from Thales. To date, more than one thousand units have been manufactured. The TV SIRIUS-LW detector (20µm pitch 640×512 IDDCA) is integrated in the Catherine-MP thermal imager from Thales. To date, several hundreds of units have been manufactured. We will discuss in this paper statistical results of these productions, which highlight the stability of the TRT QWIP technology.

Thanks to this mature technology, TRT and Sofradir have been able to increase the QWIP wafer size from 3 inches to 4 inches, without any impact on yields and FPA performances.

A dual-band MW-LW QWIP detector (25µm pitch 384×288 IDDCA) is currently under development. We will present in this paper its latest results.

8353-103, Session 18

Design and development of carbon nanotube-based microbolometer for IR imaging applications

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EO/IR Sensors and imagers using nanostructure based materials are being developed for a variety of Defense Applications. In this paper, we will discuss recent modeling effort and the experimental work under way for development of next generation carbon nanostructure based infrared detectors and arrays. We will discuss detector concepts that will provide next generation high performance, high frame rate, and uncooled nano-bolometer for MWIR and LWIR bands. The critical technologies being developed include carbon nanostructure growth, characterization, optical and electronic properties that show the feasibility for IR detection. Experimental results on CNT nanostructures will be presented. We will discuss the path forward to demonstrate enhanced IR sensitivity and larger arrays.

8353-104, Session 18

Nano-antenna-enabled MWIR FPAs

D. W. Peters, P. Davids, J. F. Klem, Sandia National Labs. (United States)

We demonstrate the effects of integrating a nanoantenna to a midwave infrared (MWIR) focal plane array (FPA). We model a device with a nanoantenna fabricated in close proximity to the active material of a photodetector. This proximity allows us to take advantage of the concentrated plasmonic fields of the nanoantenna. However, photodetector geometries and fabrication processes must be altered to accommodate the nanoantenna structure.

The nanoantenna converts freespace plane waves to surface plasmons bound to a metal surface. These plasmonic fields are concentrated in a small volume near the metal surface. Field concentration allows a thinner layer of absorbing material to be used in the photodetector design. A thinner layer of absorbing material promises improvements in cutoff wavelength and dark current (higher operating temperature).

While the nanoantenna concept may be applied to any active material, we chose to integrate the nanoantenna with an InAsSb nBn photodiode. The geometry of the detector is optimized to best utilize the electric field profile generated by the nanoantenna.

The electric field profiles in the photodetector active layers are determined by finite difference time domain simulation. These fields indicate regions where carriers are produced. The carrier generation profile then determines the geometry of the photodetector layers. Iteration between nanoantenna simulation and detector modeling optimize a structure.

We will discuss the design and optimization process and the fabrication process challenges.

8353-106, Session 18

Lifetime prediction in vacuum packaged MEMS provided with integrated getter film

F. Siviero, A. Bonucci, A. Conte, M. Moraja, SAES Getters S.p.A. (Italy); O. Gigan, TRONICS Microsystems (France); I. Thomas, Thales Avionics S.A. (France)

Thin-film getter integration is one of the key technologies enabling the development of a wide class of MEMS devices, including IR microbolometers, where stringent vacuum requirements must be satisfied to achieve the desired performances and preserve them for the entire lifetime.

Despite its importance, the question about lifetime prediction is still very difficult to answer in a reliable way. Attempts to follow an approach heavily based on mathematical simulations may result in large errors, due to the lack of knowledge of the real device complexity and propagation of uncertainty on the input data.. Here we present an experimental approach to the evaluation of lifetime, which gives emphasis to the investigation on real devices and the use of a simple and flexible model.

For a given MEMS and getter design, three main factors cooperate in determining the pressure evolution: the gas load of the production process, outgassing and leaks. In order to study these contributions, an accelerated life test is performed varying both the storage conditions and the getter area. The hermeticity is evaluated by means of specific leak testing, while MEMS behavior during the ageing test is studied monitoring device functional parameters and by residual gas analysis (RGA). These results are the inputs of a suitable model allowing extrapolating the device lifetime in operative conditions, based on the feedback from real devices in the accelerated test, reducing the uncertainty of error propagation. A test vehicle based on a resonator device has been used. Preliminary results of our approach will be shown.

8353-107, Session 18

High-speed, large-area, p-i-n InGaAs photodiode linear array at 2-micron wavelength

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Space-based detection of small molecules such as CO2 and H2O is an essential tool for monitoring ocean dynamics, cloud cover, and atmospheric greenhouse gases. Previously, lattice-mismatched InGaAs photodiode linear arrays have been employed to image these molecules, which have strong spectral signatures in the 1.5 to 2 um wavelength range. Most of these systems operate the photodiodes at near-photovoltaic mode, i.e. close to zero bias, and at low temperatures to minimize the readout noise emanating from the photodiodes' dark current. With the advances in high-speed read-out electronics, it has become feasible to reduce the overall noise by employing small integration time in the range of 1ns, provided such speeds can be supported by the photodiodes' bandwidth. Such a photodiode design is made especially challenging when a large device active area is simultaneously required to allow high free-space coupling efficiency.

We present 16-element and 32-element lattice-mismatched InGaAs photodiode arrays having a cut-off wavelength of ~2.2um at room temperature. Each pixel of the 32-element array has an active area of 100um x 200um and demonstrates a capacitance of 2.5pF at 5V reverse bias, thereby allowing a RC-limited bandwidth of ~1.2GHz for a 50 ohm load. At room temperature, each pixel demonstrates a dark current of 25uA and does not limit the overall noise performance for a read-out amplifier having >2pA/√Hz of excess input equivalent noise. Moderate cooling of the photodiode array to 200K is expected to make its dark current contribution negligible for a read-out amplifier noise of ~1pA/√Hz.

8353-109, Session 18

NIR/LWIR dual-band infrared photodetector with optical addressing

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A near infrared (NIR) and long-wavelength infrared (LWIR) dual-band infrared photodetector, which can switch detection bands with light bias, is demonstrated at 77 K. The demonstrated simple optical addressing scheme allows more bands to be added to the existing multi-band infrared photodetector designs. When conventional multi-band detector schemes are utilized in infrared focal plane arrays (FPA), processing and electrical biasing becomes more and more complex and expensive. They often need more than two terminals per pixel for readouts, or more sophisticated electrical bias magnitude and/or polarity switching circuits. On the contrary, the demonstrated scheme uses the simplest readout ICs and does not need modification of electrical connections and biasing, and consists of series connected photodetectors for different bands. The basic operating principle of the scheme is that without light bias, shorter wavelength detector limits the total current and thus device operates in NIR mode. With light bias on the NIR detector, the LWIR detector becomes the current limiting device and the device then operates in LWIR mode. Detailed analysis of the circuits, crosstalk and over device performance has shown that the device is suitable for imaging applications. Secondary effects such as extra heat load on cryogenic cooler, dynamic range limit, optical luminescence coupling and optical cross-talk are also investigated. Compatibility with different material platforms is reviewed. Optimal FPA designs with maximum pixel fill factor using single indium-bump per pixel are proposed for three or more band infrared photodetectors that are able to cover UV, visible, NIR, SWIR, MWIR and LWIR bands.

8353-136, Session 18

InAs/InAsSb Type-II superlattice: a promising material for middle-wavelength and long-wavelength infrared applications

E. H. Steenbergen, O. O. Cellek, H. Li, X. Shen, Z. Lin, D. Ding, S. Liu, Q. Zhang, H. S. Kim, L. Ouyang, J. Fan, Z. He, P. Webster, S. R. Johnson, D. J. Smith, Y. Zhang, Arizona State Univ. (United States)

Type-II superlattice (T2SL) infrared photodetectors are theoretically expected to offer higher operating temperatures than those made of HgCdTe. Our recent breakthrough shows that InAs/InAsSb T2SL structures have a minority carrier lifetime greater than 412 ns, which is an order of magnitude longer than that for conventional InAs/Ga(In)Sb T2SLs in the long wavelength infrared (LWIR) band at 77 K [1]. The InAs/InAsSb T2SL structures are strain balanced and cover a broad band from 4~12 m with optical properties that are either comparable or superior to those of InAs/Ga(In)Sb T2SLs. The samples are grown by MBE on (100) GaSb substrates, with the InAs/InAsSb T2SL layers sandwiched between two AlSb barriers. Transmission electron microscopy (TEM) results demonstrate excellent crystallinity and interface quality. X-ray diffraction (XRD) measurements show that the T2SL structures have repeatable zeroth-order FWHM values as low as 20 arcsec, a value that is limited by the XRD machine resolution. The realization of unrelaxed strain-balanced InAs/InAsSb T2SL structures on GaSb substrates are confirmed by XRD analysis. Photoluminescence (PL) peak wavelengths of 4~12 m are observed at 12 K from various samples. The PL results are in good agreement with theoretical calculations using the Kronig-Penney model. The observed longer carrier lifetime and high structural and optical quality are attributed to the lack of Ga in the superlattice, providing much a simpler interface configuration and less complex MBE growth. We anticipate that these materials will enable higher performance infrared photodetectors grown on large area GaSb substrates.

[1] E. H. Steenbergen, et al. Appl. Phys. Lett., in press (2011).

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8353-146, Session 18

An uncooled microbolometer focal plane array using bias heating for resistance nonuniformity compensation

M. Tepegoz, A. Oguz, A. Toprak, S. U. Senveli, E. Canga, Y. Tanrikulu, T. Akin, Middle East Technical Univ. (Turkey)

This paper presents the performance evaluation of a unique method called resistance nonuniformity compensation using bias heating (RNUC-BH). The RNUC-BH method utilizes a configurable bias heating duration for each pixel in order to minimize the readout integrated circuit (ROIC) output voltage distribution range. The outputs of each individual pixel in a microbolometer differ from each other by a certain amount due to the resistance non-uniformity throughout the FPA, which is an inevitable result of the microfabrication process. This output distribution consumes a considerable portion of the available voltage headroom of the ROIC unless compensated properly. The conventional compensation method is using on-chip DACs to apply specific bias voltages to each pixel such that the output distribution is confined around a certain point. However, on-chip DACs typically occupy large silicon area, increase the output noise, and consume high power. The RNUC-BH method proposes modifying the resistances of the pixels instead of the bias voltages, and this task can be accomplished by very simple circuit blocks. The simplicity of the required blocks allows utilizing a low power, low noise, and high resolution resistance non-uniformity compensation operation. A 9-bit RNUC-BH structure has been designed, fabricated, and tested on a 384x288 microbolometer FPA ROIC on which 35um pixel size detectors are monolithically implemented, in order to evaluate its performance. The compensation operation reduces the standard deviation of the ROIC output distribution from 470 mV to 9 mV under the same readout gain and bias settings. The analog heating channels of the RNUC-HB block dissipate around 4.1 mW electrical power in this condition, and the increase in the output noise due to these blocks is lower than 10%.

8353-111, Session 19

IR CMOS: infrared enhanced silicon imager

M. U. Pralle, J. E. Carey, H. Haddad, SiOnyx Inc. (United States)

SiOnyx has developed a CMOS image sensor with enhanced infrared sensitivity. The technology deployed in this remarkable device is based on SiOnyx's proprietary ultrafast laser semiconductor process. We have established a high volume manufacturing process while maintaining complete compatibility with standard CMOS image sensor process flows. The enhanced performance proves the viability of a highly scalable low cost digital infrared sensor. The spectral sensitivity is from 400 to 1200 nm with measured quantum efficiency improvements of more than 4x at 940 nm. Pixel performance metrics will be discussed.

8353-112, Session 19

Development of low-flux SWIR radio-imaging systems to study nightglow emission

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In this paper, we report the development of low flux SWIR (short wavelength infrared) radio-imaging systems to study the irradiance of the night sky. This radiation, also named nightglow emission, is mainly due to the desexcitation of hydroxyl molecules in the upper atmosphere (~85km). It is present in the visible range and reaches its maximum value in the short wavelength infrared band between 1.4 and 1.8µm. The nightglow may be an interesting additional light source for night vision systems in moonless or cloudy sky conditions. The experimental setup consist of two sensors: the first one was placed on an azimuth-elevation programmed gimbal ; the second one was placed in a fixed location and dedicated to temporal studies. The SWIR radio-imaging systems are based on 320x256 30µm pitch low flux HgCdTe IRFPAs developed by the CEA/LETI and Sofradir. They are sensitive in the 1.0-1.8µm wavelength range, cooled at liquid nitrogen temperature (78K) and respectively based on 25mm F/1.4 and 8mm F/1.3 commercial lenses. We studied the nightglow emission as a function of azimuth, elevation and time. We also used three different long-pass filters (1.4µm, 1.5µm and 1.6µm cut-on wavelength) to get some additional information about the spectral irradiance of the nightglow. In this paper, we describe the radio-imaging systems developed at Onera, our experimental setup and present some results of the measurement campaigns that we made at the Haute-Provence and du Pic du Midi Observatories in France and at the European Southern Observatory site of La Silla in Chile.

8353-114, Session 19

Development of the Compact InfraRed Camera (CIRC) for earth observation

E. Kato, H. Katayama, M. Naitoh, M. Harada, R. Nakamura, R. Sato, Japan Aerospace Exploration Agency (Japan)

We have developed the compact infrared camera (CIRC) with an uncooled infrared array detector (microbolometer) for space application. The main mission of the CIRC is the technology demonstration of the wildfire detection using the microbolometer. Wildfires are major and chronic disasters affecting many countries, especially in the Asia-Pacific region, and the situation may get worse with global warming and climate change.

The detector of the CIRC has a large format (640×480) microbolometer to obtain a wide field of view. This is the largest format ever used in Earth observations from space. Microbolometers have an advantage of not requiring cooling systems such an a mechanical cooler, and is suitable for resource-limited sensor systems or small satellites. Additionally, by employing athermal optics and shutter-less system, the CIRC achieves small size, light weight and low electrical power. The CIRC is also designed based on a commercial infrared camera, and is employing commercial-off-the-shelf (COTS) parts to reduce cost and time for development.

The CIRC will be carried as a technology demonstration payload of ALOS-2 and ISS/JEM, which will be launched in 2013. We have developed the CIRC PFM (Proto Flight Model), and conducted experiments for calibration. In this presentation, we show the verification results of the athermal characteristics, and the calibration in the case of shutter-less system.

8353-139, Session 19

Application of advanced IR-FPA in high-sensitivity pushbroom SWIR hyperspectral imager

Y. Wang, J. Wang, X. Zhuang, S. Wang, Shanghai Institute of Technical Physics (China)

A high sensitivity push-broom hyperspectral imager with a 500x256 stirling cooler detector is presented. It is a dispersive imaging spectrometer with a fused-silica prism. Thanks to advanced read out integrated circuit(ROIC) of the FPA, the system is versatile in spectral line gain, band line selecting, background reference line. The agile design enable the instrument to get high sensitivity and high radiometric accuracy. The detail principle of the apparatus is given. The measurement of performance is shown. Some interesting experiment result is also presented. The method and result will benefit high sensitivity infrared hyspectral imager.

8353-140, Session 19

Location precision analysis of stereo thermal anti-sniper detection system

Y. He, Y. Lu, Y. Hou, W. Jin, X. Zhang, Beijing Institute of Technology (China)

Anti-sniper detection devices are the urgent requirement in modern warfare. The precision of the anti-sniper detection system is especially important. This paper discusses the location precision analysis of the anti-sniper detection system based on the intersecting optical axis dual-thermal imaging system. It mainly discusses the following two aspects which produce the error: the digital quantitative effects of the camera; effect of estimating the coordinate of bullet trajectory and muzzle flash according to the Infrared images in the process of image matching. The formula of the error analysis is deduced according to the method of intersecting optical axis stereo vision model and digital quantitative effects of the camera. From this, we can get the relationship of the detecting accuracy corresponding to the system's parameters, which include the distance between the bullet and the perpendicular bisector of the two infrared cameras, the angle of the two optical axis of the infrared cameras. According to the distance of the bullet images in each frame of the infrared images and the position of the muzzle flash we can match the images which caught by two infrared cameras. Then, the bullet's location precision is also analyzed by estimating the coordinate of bullet trajectory and muzzle flash. After the theoretical analysis, we also do the simulation to verify it.. In the simulation we build the 3D model of the bullet trajectory in different positions and directions artificially and select some points in the model according to the speed of the bullet. Then we perform the coordinate transformation, quantization process and the pixel coordinates estimation for these points. Finally, we get the pixel coordinates points and finish the 3D reconstruction of these pixel coordinates. The precision analysis was done between the ideal 3D model and the reconstruction result. The analysis in this paper provides the theory basis for the error compensation algorithms which are putting forward to improving the accuracy of 3D reconstruction of the bullet trajectory and muzzle flash in the anti-sniper detection devices.

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8354-01, Session 1

Excitation source considerations for thermographic NDT

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Numerous alternatives for excitation in the thermographic NDT process have been successfully demonstrated and implemented, ranging from solar loading to sub-millisecond flash systems. These vary widely, not only in the practical terms of cost, size and complexity, but also in the area, amplitude and time scale of the excitation. For a particular application, the latter 3 factors must be matched to the test component material and geometry, as well as the noise characteristics of the IR camera that is to be used. Using these criteria, we have evaluated a number of source / camera combinations and developed a metric for comparison for a given application.

8354-02, Session 1

Thermography inspection for early detection of composite damage in structures during fatigue loading

J. N. Zalameda, E. R. Burke, NASA Langley Research Ctr. (United States); J. Seebo, Lockheed Martin Corp. (United States); P. Johnston, C. Wright, NASA Langley Research Ctr. (United States); J. Bly, Lockheed Martin Corp. (United States)

Advanced composite structures are commonly tested under controlled loading. Understanding the initiation and progression of composite damage under load is critical for validating design concepts and structural analysis tools. Thermal nondestructive evaluation (NDE) is used to detect and characterize damage in composite structures during fatigue loading. Both passive and active thermography are used to detect damage initiation and growth. The passive thermography technique detects damage during fatigue loading. The active flash thermography inspection is performed while a small static torsion load is applied. A difference image processing algorithm is demonstrated to enhance damage detection and characterization by removing thermal variations not associated with defects. In addition, a one-dimensional multi-layered thermal model is used to characterize damage. Lastly, the thermography results are compared to other inspections such as non-immersion ultrasonic inspections and computed tomography X-ray.

8354-03, Session 1

Characterisation of composites by noninvasive IR imaging techniques

N. P. Avdelidis, National Technical Univ. of Athens (Greece) and Univ. Laval (Canada); C. Ibarra-Castanedo, H. Bendada, X. P. V. Maldague, Univ. Laval (Canada)

Infrared thermography has been used for the non destructive testing (NDT) of materials and components for several years now. The main advantage of thermography over classical NDT techniques resides in the possibility of inspecting large areas in a fast and safe manner without needing to have access to both sides of the component. Nevertheless, infrared thermography is limited to the detection of relatively shallow defects (a few millimetres under the surface), since it is affected by 3D heat diffusion. However, the most common types of anomalies found on composites, such as delaminations, disbonds, water ingress, node failure and core crushing, can be effectively detected and sometimes quantified using active thermographic techniques. This research work evaluates the potential of various infrared thermography (IRT) approaches, as well as near infrared (NIR) vision for assessing defects (i.e. impact damage, inclusions for delaminations, etc) on various types of composites.

8354-04, Session 1

Water ingress detection on honeycomb sandwich panels by passive infrared thermography using a high-resolution imaging camera

C. Ibarra-Castanedo, Univ. Laval (Canada); L. Brault, Telops (Canada); M. Genest, National Research Council Canada (Canada); V. Farley, Telops (Canada); X. P. V. Maldague, Univ. Laval (Canada)

Water ingress on honeycomb structures is of great concern for the civil and military aerospace industry. Pressure and temperature variations during take-off and landing produce considerable stress on aircraft structures, promoting moisture ingress (by diffusion through fibers or by direct ingress though voids, cracks or unsealed joints) into the core. The presence of water (or other fluids such as kerosene, hydraulic fluid and de-icing agents) in any of its forms (gas vapor, liquid or ice) promotes corrosion, cell breakage, and induce composite layer delaminations and skin disbounds.

In this study, test specimens were produced from unserviceable parts from a military aircraft. In order to simulate atmospheric conditions during landing, selected core areas were filled with measured quantities of water and then frozen in a cold chamber. The specimens were then removed from the chamber and monitored for up to an hour as they warm up using a cooled high-resolution infrared camera and an uncooled microbolometer camera for reference. Results have shown that detection and quantification of water ingress on honeycomb sandwich structures by passive infrared thermography is possible using both cameras. The use of a high-resolution camera however, considerably improves detection, resolution and characterization of areas containing water. Furthermore, high spatial resolution allows imaging honeycomb cells distribution, which is of paramount importance to precisely identify damaged areas and eventually perform the necessary repairs.

8354-05, Session 1

Inspection of composite structures using line scanning thermograph

O. Ley, Physical Acoustics Corp. (United States)

This work deals with the non destructive analysis of different composite structures and composite materials industry using Line Scanning Thermography (LST), a non-contact inspection method based in dynamic thermography. The LST technique provides a quick and efficient methodology to scan wide areas rapidly; the technique has been used on the inspection of composite propellers, sandwich panels, motor case tubes and wind mill blades, among others.

In LST a line heat source is used to thermally excite the surface under study while an infrared detector records the transient surface temperature variation of the heated region. Line Scanning Thermography (LST), has successfully been applied to determine the thickness of metallic plates and to assess boiler tube thinning; as well as to determine extent of impact damage in laminate composites.

In this presentation the LST protocols developed for the detection of sub-surface defects in different composite materials commonly used in aerospace applications, wind turbines and metallic plates will be presented. In most cases the thermal images acquired using LST will be compared with ultrasonic c-scans. In this presentation the fundamentals of LST will be discussed, as well as the limitations of this technique for NDT inspection.

8354-06, Session 1

Automated quality assurance based on thermographic signal reconstruction

S. M. Shepard, Thermal Wave Imaging, Inc. (United States)

Since its introduction in 1999, the Thermographic Signal Reconstruction (TSR) method has become a widely used approach to analysis and processing of data from flash, step, scanned and acoustically excited thermography data. Perhaps the most significant feature of the TSR approach is its use of logarithmic derivatives as a basis for signal analysis. The ability of TSR to evaluate each pixel time history independently of neighboring pixels represents a significant departure from evaluation of image contrast, which requires comparison of a flaw and intact background. This capability has made it possible to extend the domain of thermography beyond NDT, where flaw detection is the objective, to quality assurance, which requires the detection of variations or anomalies that may not result in a discrete flaw that could be identified with a contrast approach. Examples of TSR-based quality assurance power generation and composite manufacturing will be presented.

8354-07, Session 1

Matched excitation for thermal nondestructive testing of carbon fiber reinforced plastic materials

R. Mulaveesala, G. V. Subbarao, M. Amarnath, PDPM IIITDM Jabalpur (India)

In recent years composite materials are widely used in numerous applications in the fields of aerospace, civil and mechanical engineering. Presence of defects like voids and delaminations developed during manufacturing stage reduces their in-service applications, which demands a reliable non destructive technique for thorough evaluation of these materials. Infrared thermography (IRNDT) which offers a quick, reliable and non contact evaluation for health monitoring of structures with its whole field, non invasive detection capabilities makes it to be a suitable testing and evaluation method of composites. Active thermographic studies provide deeper subsurface details and reduce non uniform emissivity problems in defect detection. In this contribution analysis of subsurface anomalies has been carried out by probing a suitable frequency component with sufficient energy. This paper highlights the comparative analysis of different thermographic schemes on the basis of supplying equal energy to the chosen frequency used for the analysis of given carbon fiber reinforced plastic(CFRP) sample used in experimentation. Experiments have been carried out to find the detection ability of different excitation schemes and comparisons have been made by taking signal to noise ratio (SNR) of the defects into consideration.

8354-08, Session 1

Detecting corrosion in thick metals by active thermal nondestructive testing

V. P. Vavilov, A. O. Chulkov, Tomsk Polytechnic Univ. (Russian Federation)

Several studies have been devoted to the detection and evaluation of corrosion in metals by using active Thermal NDT (TNDT). Areas with wall thinning (material loss) are characterized by increased temperature, and the amplitude and temporal evolution of the temperature increase can provide quantitative information about the size of the corrosion defect. The most successful use of TNDT for corrosion detection has been on thin (1-2 mm) aluminum used in airplane skins. One difficulty in using this technique on aluminum is the low emissivity of the metal, which tends to reflect the optical radiation heating pulse, while providing only a weak emission of its own radiation, which is the data necessary for the process. Another difficulty is the short observation times required, which require the use of high-speed IR cameras. When testing thick metallic targets, such as storage tanks and containers made of 2-20 mm thick steel, the emissivity and observation time problems do not appear to be so challenging as in the case of aluminum. But the thermal stimulation must be fairly powerful to ensure the production of detectable temperature signals. In the case of relatively thick steel, the detection limit is typically reported to be about 20% material loss compared to a few percent in the case of thin aluminum. The basic theory of TNDT of corrosion in thick metals has been reported earlier by the authors in collaboration with S.Marinetti, E.Grinzato and P.Bison (ITC-CNR, Italy).

In this paper, theoretical results are reduced to simple recommendations that allow reliable defect characterization, and there is an extended section showing experimental results of thermal stimulation by several methods, including convective, radiant and contact. In addition, there is a discussion on choosing an optimum data processing algorithm.

8354-09, Session 1

Development of nondestructive crack inspection technique for conveyance roll using vibro-thermography

D. Imanishi, Y. Nishina, Y. Yoshinaga, JFE Steel Corp. (Japan)

In recent study, active thermography has reached a high status as an easy and speedy defects inspection method in a NDT field. This paper newly proposes a non-disassembly and non-contact NDT method using a Vibro-Thermography for detecting and evaluating of fatigue cracks at neck parts of the conveyance roll in the steel making plant. In this method, fatigue cracks are detected as localized high temperature areas caused by friction and collision at crack surfaces with an infrared camera, applying a high-amplitude ultrasonic vibration. In this paper, the most suitable nose-shape of horn type transducer, which is contacted with the curved roll surface, is developed for an effective propagation of ultrasonic vibration. In the case of the roll surface is covered with lubricating grease or dust, the crack detectability is shown. Self reference lock-in data processing technique is applied for improvement of signal noise ratio in the crack detection process. This technique makes it possible to perform correlating process without an external reference signal. Time and cost saving inspection method in the neck part of conveyance roll is carried out using this NDT technique.

8354-10, Session 1

Nondestructive evaluation of concrete structures by nonstationary thermal wave imaging

R. Mulaveesala, A. Muniyappa, S. S. B. Panda, R. N. Mude, PDPM IIITDM Jabalpur (India)

The strength of concrete structures degrades drastically if a de-bond or cracks exists in them, e.g. runways, bridges, bases of buildings, etc. These defects can results catastrophic structural failure unless their presence is detected and their effects are assessed. Which makes the inspection of concrete structures is a crucial and challenging aspect in the area of damage prediction and health monitoring. Present work highlights the applicability of Thermal Non-destructive Testing (TNDT) for inspection of concrete specimens. Infrared TNDT involves mapping of surface temperatures as heat flows from and/or through a test sample, for detecting surface and subsurface features (voids, cracks etc.). It is a fast, whole field, and non-contact method for defect detection. Since most solids conduct heat, TNDT has the potential for wide use in defect detection in a variety of solid materials. This paper highlights

an experimental investigation of rebar corrosion by non-stationary thermal wave imaging. Experimental results have been proven, proposed approach is an effective technique for identification and quantification of corrosion in rebar in the concrete samples.

8354-11, Session 2

Nonstationary thermal wave imaging techniques for inspection of wooden materials

R. Mulaveesala, V. N. P., D. Ravi, M. Amarnath, PDPM IIITDM Jabalpur (India)

Infrared non-destructive testing and evaluation is an emerging approach due to its capability to test wide verity of solid materials such as metals, composites and semiconductors of industrial interest. This paper presents inspection of wooden materials which are widely used in building industries, naval architecture, construction and industrial applications. So this demands thorough inspection and evaluation approaches preferably through remote and nondestructive testing (NDT) methods. Of course, in most of the applications wood is used as it is, but still there is a need to test wood to detect knots, delaminations and other defects which influences its in-service capabilities. Even though various non destructive methods such as optical, ultrasonic and radiography are widely used to inspect wooden materials, infrared imaging has its own advantage due to its safe, whole filed, fast and non contact inspection capabilities. This paper describes the applicability of the thermal wave imaging (TWI) method for inspection of ply wood materials. Present work highlights applicability of non stationary thermal wave imaging named as Frequency Modulated Thermal Wave Imaging approach for finding out the hidden defects. Capability of the proposed method and its defect detection capabilities have been highlighted through experimental results.

8354-12, Session 2

C/C composite brake disk nondestructive evaluation by IR thermography

T. P. Chu, A. Poudel, P. Filip, Southern Illinois Univ. Carbondale (United States)

This paper discusses about the non-destructive evaluation of thick Carbon/Carbon composite aircraft brake disks by using transient infrared thermography (IRT) approach. Thermal diffusivity measurement technique was applied to identify the subsurface anomalies in thick C/C brake disks. In addition, finite element analysis (FEA) modeling was used to determine the transient thermal response of the C/C disks that were subjected to flash heating. Series of finite element models were built and thermal responses with various thermal diffusivities subjected to different heating conditions were investigated. Experiments were conducted to verify the models by using custom built in-house IRT system. The analysis and experimental results showed good correlation between thermal diffusivity value and anomalies within the disk. It was demonstrated that the flash setup can be effectively used to obtain the whole field thermal diffusivity value.

8354-13, Session 2

Thermal measurement of brake pad linning surfaces during the braking process

T. Piatkowski, H. Polakowski, M. Kastek, P. Baranowski, K. Damaziak, J. Malachowski, Military Univ. of Technology (Poland)

One of the most important systems in cars and trucks are brakes. The braking temperature on a lining surface can rise above 500°C. This shows how linings requirements are so strict and, what is more, continuously rising. Besides experimental tests, very supportive method for investigating processes which occur on the brake pad linings are numerical analyses. Experimental tests were conducted on the test machine called IL-68. The main component of IL-68 is so called frictional unit, which consists of: rotational head, which convey a shaft torque and where counter samples are placed and translational head, where samples of coatings are placed and pressed against counter samples. Due to the high rotational speeds and thus the rapid changes in temperature field, the infrared camera was used for testing. The paper presents results of analysis registered thermograms during the tests with different conditions. Furthermore, based on this testing machine, the numerical model was developed. In order to avoid resource demanding analyses only the frictional unit (described above) was taken into consideration. Firstly the geometrical model was performed thanks to CAD techniques, which in the next stage was a base for developing the finite element model. Material properties and boundary conditions exactly correspond to experimental tests. Computations were performed using a dynamic LS-Dyna code where heat generation was estimated assuming full (100%) conversion of mechanical work done by friction forces. Paper presents the results of dynamic thermomechanical analysis too and these results were compared with laboratory tests.

8354-14, Session 3

Thermographic imaging of the space shuttle during re-entry using a near-infrared sensor

J. N. Zalameda, T. J. Horvath, R. V. Kerns, NASA Langley Research Ctr. (United States); J. C. Taylor, T. S. Spisz, D. M. Gibson, The Johns Hopkins Univ. Applied Physics Lab. (United States); E. J. Shea, Futron Corp. (United States); D. Mercer, Stinger Graffarian Technologies, Inc. (United States); R. J. Schwartz, Analytical Mechanics Associates, Inc. (United States); S. Tack, Naval Air Warfare Ctr. Weapons Div. (United States); B. C. Bush, Photon Research Associates Inc. (United States); R. F. Dantowitz, Celestial Computing, Inc. (United States)

High resolution calibrated infrared imagery of the Space Shuttle was obtained during hypervelocity atmospheric re-entry of the STS-119, STS-125, STS-128, STS-131, STS-132, and STS-133 missions. This data has provided information on the distribution of surface temperature and the state of the airflow over the windward surface of the Orbiter during descent. The thermal imagery complemented data collected with onboard surface thermocouple instrumentation. The spatially resolved global thermal measurements made during the Shuttle's hypersonic re-entry will provide critical flight data for reducing the uncertainty associated with present day ground-to-flight extrapolation techniques and current state-of-the-art empirical boundary-layer transition or turbulent heating prediction methods. Laminar and turbulent flight data is critical for the validation of physics-based, semi-empirical boundary-layer transition prediction methods as well as stimulating the validation of laminar numerical chemistry models and the development of turbulence models supporting NASA's next-generation spacecraft. In this paper we provide details of the NIR imaging system used on both land and air based imaging assets. The paper will discuss calibrations performed on the NIR imaging systems that permitted conversion of captured radiant intensity (counts) to temperature values. Image processing techniques including image registration and averaging, image histogram analysis, and 3-dimensional mapping will also be presented.

8354-15, Session 3

Processing ground-based, near-infrared imagery of space shuttle reentries

T. S. Spisz, J. C. Taylor, D. M. Gibson, S. W. Kennerly, K. Osei-Wusu, The Johns Hopkins Univ. Applied Physics Lab. (United States); T. J. Horvath, J. N. Zalameda, R. V. Kerns, NASA Langley Research Ctr. (United States); E. J. Shea, Futron Corp. (United

States); D. Mercer, Raytheon Technical Services Co. (United States); R. J. Schwartz, Analytical Mechanics Associates, Inc. (United States); R. F. Dantowitz, M. J. Kozubal, Celestial Computing, Inc. (United States)

Ground-based high-resolution, calibrated, near-infrared imagery of the Space Shuttle during reentry has been obtained as part of NASA's HYTHIRM (Hypersonic Thermodynamic InfraRed Measurements) project. The long-range optical sensor package called MARS (Mobile Aerospace Reconnaissance System) was positioned in advance to acquire and track the shuttle re-entry. Two sets of imagery have been acquired and processed: 1) STS-131 when Shuttle Discovery was at 192 kft at Mach 15, and 2) STS-134 when Shuttle Endeavour at 136 kft at Mach 6. The challenges presented in processing a high-angular rate, ground-to-air image data collection include management of significant frame-to-frame motions, motion-induced blurring, changing orientations and ranges, atmospheric conditions, and sky backgrounds. This paper describes the processing of the imagery, building upon earlier work from airborne imagery collections of several prior shuttle missions. Our goal is to reduce the detrimental effects due to motion, vibration, and atmospherics for image quality improvement, without compromising the quantitative integrity of the data, especially local intensity variations. Our approach is to select and utilize only the highest quality images, register several co-temporal image frames to a single image frame, and then add the registered frames to improve image quality and reduce noise. The registered and averaged intensity images are converted to radiance values using calibration data, and then the temperatures on the shuttle's windward surface are computed. These temperature images will be shown as well as comparisons with thermocouples at different points along the shuttle.

8354-16, Session 3

Spatially resolved infrared spectra of jet exhaust from an F109 turbofan engine

J. L. Harley, K. C. Gross, Air Force Institute of Technology (United States); C. F. Wisniewski, A. J. Rolling, U.S. Air Force Academy (United States)

There is a strong interest in diagnosing engine performance problems and maintenance needs using rapid optical techniques instead of expensive, time-consuming mechanical inspection. To begin investigating the feasibility of optical diagnostics, a Telops Hyper-Cam mid-IR (1.5-5.5 µm) imaging Fourier-transform spectrometer collected spatially-resolved spectral measurements of jet exhaust from an F109 turbofan engine. The initial scope of this work is to understand what information content about the turbulent jet flow field is revealed in the measured spectra. The engine burned JP-8 jet fuel and was operated at various thrust levels. The influence of the thrust level on the measured spectra will be discussed. A simple radiative transfer model which assumes axial symmetry is being developed so that radial temperature and concentration profiles might be extracted from the measured spectra. The flow field is unsteady, and intensity fluctuations introduce artifacts in the measured spectra. Methods to minimize the impact of intensity fluctuation artifacts on the spectral interpretation will be discussed.

8354-17, Session 4

High-resolution texturing of building facades with thermal images

M. Scaioni, E. Rosina, L. Barazzetti, M. Previtali, Politecnico di Milano (Italy)

The combination of laser scanner surveying, photogrammetric imagery and IR thermograhpy allows the generation of 3D multispectral models useful for the localization, visualization, and analysis of anomalies in buildings such as damage of finishing, corrosion of the concrete reinforcement, heating loss/ lack of insulation, moisture diffusion, etc.

As the state of the art comprehends some basic techniques for mapping IRT imagery on 3D models, many developments are required to increase the automation and reliability of testing procedures to localize/quantify specific defects on finishing material

This paper presents a methodology ables to map a block of IR thermal images on 3D models created with terrestrial laser scanning. The method stands out from other approaches, which are mainly based on homography or space resection techniques. Here a rigourous photogrammetric orientation is used, through an integrated bundle adjustment solution including both RGB, thermal IR, and Near IR data. Also a coplementary solution based on the use of a calibrated "bi-camera" system has been developed to overcome problem in ares with low-textures. Instead of mapping IR images directly, temperature values are used. Consequently, each facade will be textured with 3D information on the surveyed temperature. Two approaches are used for data interpretation: (1) a triangulated model is adopted to visualize 3D spatial information; this allow the analysis of 3D heating diffusion on the surface. (2) A raster temperature grid is computed through interpolation; this enables analytical processing of georeferenced thermal information (e.g. thermal gradient analysis, comparison of thermal data gathered at different epochs, etc.).

Expected results are the improvements of diagnostics and survey as well as shortening the time from data analysis to preliminary design. Moreover, the availability of results in the preliminary phase allow to address the executive projects since the beginning, avoiding expensive changes of orientation in the further steps of the study/projects.

Another result is the possibility of applying the method for monitoring the damage in the preservation plan and to prioritize the interventions in a full scale economy (e.g. the preservation of an entire historical center/villages, sites).

The approach was tested on different buildings of Politecnico di Milano, where a restoration project of facades is currently in progress.

8354-18, Session 4

An evaluation of the impact of an example of thermal bridging in buildings and a design alternative

J. M. Kleinfeld, Kleinfeld Technical Services, Inc. (United States)

Thermal Bridges act as short circuits for energy flow between conditioned interior space and the outside environment. They readily show up in infrared imaging under appropriate conditions. An example of a thermal bridge in a standard building detail and an alternate design are analyzed to predict the energy impact of the bridge and of removing it.

8354-19, Session 4

Building thermography and energy performance directive of buildings

T. T. Kauppinen, S. Siikanen, VTT Technical Research Ctr. of Finland (Finland)

Energy Performance of Buildings Directive came in to the force in Europe couple of years ago and it had an immediate effect on Building Codes in Europe. Finland have changed it`s building codes since 2007 - the insulation requirements have been tightened and the requirements have been specified. The biggest changes is energy efficient calculations and determination of energy efficiency and energy label for building.

This has caused a boom of new service providers (thermography services, air-tightness measurements and other services like new calculation tools).

Thermography is used in verification in performance of buildings. In this presentation some examples of building thermography in walk-throughenergy audits combined with the results of energy efficiency calculations are presented - also some special problems in buildings of specific use (art museum) and use of thermography to solve them.

8354-20, Session 5

Monitoring and thermal effects of relubrication of greased bearings

R. N. Wurzbach, Maintenance Reliability Group, LLC (United States)

Grease lubrication of rolling element bearings is one of the most common lubricated scenarios in industry. The exact behavior of greases while equipment is in operation is not well understood. Such greased bearings are typically hidden from direct observation, and are only monitored indirectly by housing temperature measurements, or observations of the shutdown, disassembled machine. This paper will detail studies that provide insight into thermal behavior, flow characteristics of non-newtonian greases, and changes in grease properties in operating rolling-element bearings. Measurements made with specially designed test stands include observation of operating bearings and direct temperature measurement of grease, both flowing and static, while in operation. Testing of grease properties also provides insight into the observed conditions, and is correlated to better understand strategies to monitor in-service grease lubricated bearings.

8354-21, Session 5

In-line particle measurement in a recovery boiler using high-speed infrared imaging

S. Siikanen, VTT Technical Research Ctr. of Finland (Finland); P. Miikkulainen, Andritz Oy (Finland); M. Kaarre, M. Juuti, VTT Technical Research Ctr. of Finland (Finland)

Black liquor is the fuel of kraft recovery boilers. It is sprayed into the furnace of a recovery boiler through splashplate nozzles. The operation of a recovery boiler is largely influenced by the particle size and particle size distribution of black liquor. When entrained by upwards-flowing flue gas flow, small droplet particles may form carry-over and cause the fouling of heat transfer surfaces. Large droplet particles hit the char bed and the walls of the furnace without being dried. In this study, particles of black liquor sprays were imaged using a high-speed infrared camera. Measurements were done in a functional recovery boiler in a pulp mill. Objective was to find a suitable wavelength range and settings such as integration time, frame rate and averaging for the camera. Visibility through hot gas streams was successfully obtained in mid-infrared range and temperatures, sizes, velocities and shapes of the particles could be measured inside the recovery boiler. Measurement results were coherent with measurement results of Kankkunen et.al., which were obtained from the same furnace at the same time.

8354-22, Session 5

Thermographic evaluation of hydrogenerator losses

R. P. Siniscalchi, Furnas Centrais Elétricas (Brazil); E. C. Bortoni, Univ. Federal de Itajubá (Brazil)

The calorimetric method is a standard procedure to determine power generator losses and energy conversion efficiency. The use of thermography techniques has been applied by the authors with great success. This paper presents the theoretical basis of the employed technique, with some applications, along with a discussion about improvements in the current standards, namely IEEE-std-115 and IEC-60034-2-2, to make a good use of cutting edge technologies. The presented discussions covers contributions on the determination of the heat transfer coefficient, and the consideration of losses often neglected when using conventional instrumentation.

8354-23, Session 5

Opportunities and challenges of the application of a dynamic, multispectral thermography as a means to improve the effectiveness of furnace processes in the petrochemical industry

P. Pregowski, Pregowski Infrared Services (Poland); G. Goleniewski, W. Komosa, W. Korytkowski, PKN ORLEN S.A. (Poland)

During the Thermosense XXVI conference we presented an innovative method for dynamic thermographical measurements of the pipes and walls temperatures in the petrochemical process furnaces. These measurements, based on special processing of long enough sequences of thermograms, had been performed by using typical, narrow-band filter around 3.9µm. This method allows to significantly increase both reliability and the field of measurements, especially when such surveys have to be made in the presence of hot aerosols and flames. In recent years we have worked on the adaptation of this method for improving the symmetry and optimizing the heating processes in selected furnaces. It should result both in extending cycles of work between cleaning sessions for pipes and furnaces, as well as in reducing the fuel consumption. For this purpose, the camera ThermaCAM 1000Sc was equipped with a module composed of the interference filters (with narrow bands around: 3.36µm, 3.42µm, 3.66µm, 3.89µm, 4.23µm, 4.48µm, 4.65µm) matched to the emission of several major gases, which occur in the heating medium. The rotating disc with these filters allowed the fast registration of the sequences,i.e. films consisting of several hundred or more images each, successively one after another and with low latency. These studies, by virtue of their specificity, were mainly of empirical nature. We have completed many different research programs. The paper will present both innovative and important potential of this method, as well as major constraints still to be resolved...

8354-24, Session 5

Infrared evaluation of insulated pipelines to detect water that could cause corrosion under insulation (CUI)

D. Burleigh, La Jolla Cove Consulting (United States); H. A. Sanders, Kakivik Asset Management, LLC (United States)

IR is being used to evaluate Pipelines in the Arctic zone.

Pipelines are insulated with foam and covered with a metal sheath. By various means, water can enter the sheath and become trapped in the insulation. If the water comes into contact with the steel pipe, it can cause corrosion, which can ultimately cause a pipeline leak. This is called Corrosion Under Insulation (CUI).

In additon to a loss of oil, a leak will cause environmental contamination.

IR is being used to detect water in the insulation before it causes leaks.

8354-25, Session 5

Sportswear textiles emissivity measurement: comparison of IR thermography and emissometry techniques

P. Bison, E. G. Grinzato, Consiglio Nazionale delle Ricerche (Italy); A. Libbra, A. Muscio, Univ. degli Studi di Modena e Reggio Emilia (Italy)

Two textiles are made of polypropylene (PP) and charged with Ag+ ions and Carbon powder. They differ from the color that is green for the first and blue for the second. They are compared with a third 'normal' PP

textile of green color and the same weft of the previous. The purpose is to demonstrate if the emissivity in the Infrared Long Wave band (IR-LW) of the charged textiles is increased or not due to the presence of the charging elements.

The technique consists in laying down the charged textiles to be measured and the 'normal' (the reference) one, side by side and in contact with a thick aluminum plate that is assumed to be as much isothermal as possible. Observing the two textiles (that own the same temperature) by an IR camera allows to evaluate the IR radiation emitted by their surfaces. The difference in the radiation collected by the IR camera in correspondence of the 'measured' textiles and the 'reference' one is due to the emissivity difference. This measurement is more difficult than the one for an opaque surface in so far the textiles are semitransparent and the radiation collected by the camera is due to the contribution of the textiles themselves plus the background, each one emitted with its own emissivity and weighted by the surface fraction that it covers. The test is also carried out by an IR emissometry technique, also in this case using non-standard procedures due to the semitransparent nature of the textiles.

8354-27, Session 6

Real-time object detection and tracking for night vision systems based on information fusion

N. Fragoulis, C. Theoharatos, V. Tsagaris, IRIDA Labs. (Greece)

Night vision systems are key elements in the modern warfare and security applications, since they act as force multipliers offering the potential of operating in low visibility environments, and at night.

In the proposed paper a new system for object detecting and tracking for night vision is presented. The system is based on the use of information fusion techniques combining information from infrared and optical sensors. The system is able to detect moving objects within the view of the two sensors, and track their trajectories.

The information fusion subsystem is based on IRIDA Labs' SYNTHESIS adaptable video fusion system, which uses objective evaluation measures to assess image fusion in order to adapt the fusion algorithm to the particularities of the image in the area which is under surveillance. This feature broadens significantly the applicability of the system.

The presented system is implemented on an FPGA-based embedded platform, offering re-configurability and robustness combined with real time performance.

8354-28, Session 6

Achieving thermography with a thermal security camera using uncooled amorphous silicon microbolometer image sensors

Y. Wang, C. Tesdahl, J. Owens, D. Dorn, Pelco by Schneider Electric (United States)

Advancements in uncooled microbolometer technology over the last several years have opened up many commercial applications which had been previously cost prohibitive. Thermal technology is no longer limited to the military and government market segments. One type of thermal sensor with low NETD which is available in the commercial market segment is the uncooled amorphous silicon (α-si) microbolometer image sensor. Typical thermal security cameras focus on providing the best image quality by auto tonemaping (contrast enhancing) the image, which provides the best contrast depending on the temperature range of the scene. While this may provide enough information to detect objects and activities, there are further benefits of being able to estimate the actual object temperatures in a scene. This thermographic ability can provide functionality beyond typical security cameras by being able to monitor processes. Example applications of thermography with thermal camera include: monitoring electrical circuits, industrial machinery, building thermal leaks, oil/gas pipelines, power substations, etc... This paper discusses the methodology of estimating object temperatures by characterizing/calibrating different components inside a thermal camera utilizing an uncooled amorphous silicon microbolometer image sensor. Plots of system performance across camera operating temperatures will be shown.

8354-29, Session 6

Using aerial infrared thermography to detect utility theft of service

G. R. Stockton, RecoverIR, Inc. (United States) and United Infrared, Inc. (United States) and Stockton Infrared Thermographic Services, Inc. (United States); R. G. Lucas, RecoverIR, Inc. (United States)

Natural gas and electric utility companies, public utility commissions, consumer advocacy groups, and cities across United States continue to turn a blind eye towards energy theft of service, which is in excess of $10 billion. As unemployment rates go up, the amounts for federal funding for low income heating assistance programs is cut nearly in half for 2012 and contributions to charities are down, the number of families below the poverty line who are unable to pay to heat their houses continues to rise. Some number of these people now consider theft and fraud to be an attractive option for their supply of natural gas and electricity. The proliferation of smart meters and automated meter infrastructures across our nation can do little to detect energy theft because thieves by pass the meters, jump around the meters and steal meters from abandoned houses and use them. Many utility systems were never set-up to stop these types of theft.

This paper will define the problem and present successful techniques for finding energy theft using thermal infrared from the air, computer algorithms and analysis. These techniques can be used successfully to stop theft, but only if the stakeholders across America admit the problem, and are willing to not just pass the cost of theft on to the bill-paying public.

8354-30, Session 7

Development and validation of experimental models for hyperemic thermal response using IR imaging

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A common method for diagnosing heart health condition is to analyze blood flow rate and temperature behaviors after arterial occlusion. However, multiple factors besides heart condition could affect these behaviors. The objective of this research was to identify other factors that affect blood flow and thermal response after arterial occlusion, evaluate a mathematical model to determine thermal response after arterial occlusion, and develop an experimental model for thermal response after arterial occlusion. Twenty-eight experiments were conducted with 14 subjects to determine blood and thermal responses by using plethysmography and infrared imaging after applying arterial occlusion. Possible factors affecting blood flow and thermal responses that were investigated were: Initial finger temperature, blood pressure, body temperature, gender, and age. After determining the correlation coefficient among the mentioned factors and blood flow and thermal responses after occlusion, it was determined that only initial finger temperature and blood pressure show a strong effect. A mathematical model accounting only for the convective thermal effects, but not thermal conduction effects, was developed and tested, but was found to be insufficiently accurate in describing the thermal response by means of blood flow parameters for all of the subjects tested (error>90%). A linear regression model was then developed to relate blood flow to thermal response using two thirds of the experimental data, and was tested using

one third of the data. The linear regression model was found to predict thermal response by means of blood flow response with an error rate of less than 50%.

8354-31, Session 7

Breast cancer in tough economic times, new paradigms emerging

P. Bretz, Desert Breast and Osteoporosis Institute (United States) and Desert Breast Foundation (United States); R. Lynch, Desert Breast and Osteoporosis Institute (United States)

Background: Mammography, ultrasound and MRI have been available for over forty years, including constant updates in technology. There is still no universal utilization by women, costs continue to escalate and problems persist like high false positive rates for MRI and high false negative rates for mammography. Collectively these modalities have not been able to put an end to the deaths and disfigurement caused by this disease.

Objective: To investigate the efficacy of melding two emerging technologies: pharmacogenomics and modified military digital infrared to establish their capability in diagnosing ultra-small breast cancers as well as other cancers.

Design: Analysis of prospectively collected data and biologic material.

Setting: Independent Comprehensive Breast Center

Patients: The first 500 patients who elected to proceed with combined genetics testing and infrared.

Main Outcome Measures: Earlier and correct identification of breast cancer using non-invasive and non-ionizing radiation modalities.

Result: Of the first 500 IR patients, 499 were female and 1 male. Of 550 OncoVue patients, 129 opted to undergo IR. A total of 19 were lost to follow-up. Patients who were negative on IR: 419/500 (84%).

Of these, 63/419 went to biopsy because of findings on other diagnostic modalities. Of these, 61/63 with negative IR had a negative biopsy. Of two missed cancers, one was the fault of the investigator but was included. In this series 2/500 were false negative (0.4%). The sensitivity was 96% and the specificity was 79%. In total, 46 cancers were identified including five outside the breast (e.g., 2 lung cancers). A total of 92 MRIs were done and in 71/92 patients IR and MRI agreed or 77% of the time. Of the 23% where they disagreed over a four year period IR was correct 100% of the time. Using these two modalities the smallest cancer found was 4mm.

Conclusion: Our objective was met. These two new diagnostic techniques can dramatically lower cost and provide results at least as good as older paradigms. Further research and a multicenter clinical trial are necessary to shift the paradigm of breast cancer diagnosis.

8354-33, Session 7

Investigation of thermal effects caused by interaction of laser radiation with soft tissues

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Effective laser welding of biological tissues require strict temperature control over the entire process. Allowed temperature margin is 2K around the tissue-specific coagulation temperature. Exceeding that margin can cause necrosis or make tissue welding impossible. As a result the temperature of the tissue area exposed to laser radiation have to be controlled and the power of the laser should be accordingly adjusted. By assuring stable temperature value of the treated tissue the uniform tissue connection can be achieved, which in turn causes uniform growth of collagen fibre across the cicatrix during the healing process. Additionally by keeping the temperature within allowed margin the strongest tissue weld is achieved.

The paper presents the results of the research concerning the interaction of continuous wave laser diode and pulsed Nd:YAG laser with a muscle tissue, including the description of test stand, conducted experiments and conclusions. The influence of energetic and time parameters of a laser beam on the observed thermal effects are discussed. In order to perform necessary tests the test rig was developed, fitted with two lasers: one laser diode (wavelength 970 nm) and Nd:YAG laser (wavelength 1064 nm) and a fast thermal camera (frame rate up to 1000 Hz). The applied close-up lens allowed for the visualization of tissue weld area and the temperature distribution before, during and after the welding process was recorded. It was also possible to monitor the geometrical parameters of an interaction area and the rate of temperature changes, which allowed for precise adjustment of laser beam parameters.

8354-34, Session 7

Human ear detection in the thermal infrared spectrum

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In this paper the problem of human ear detection in the thermal infrared (IR) spectrum is studied in order to illustrate the advantages and limitations of ear biometrics in dark environments. The contributions of this work are two-fold:

First, a dual-band database is assembled that consists of visible and thermal profile face images. The thermal data was collected using a high definition Middle-Wave Infrared camera that is capable of acquiring thermal imprints of human skin.

Second a fully automated, thermal imaging based ear detection method is developed for real-time segmentation of human ears.

The method is based on Haar features forming a cascaded AdaBoost classifier (modified Viola-Jones). The main advantage of the proposed method is that it is designed to reduce the learning time required by the naïve Viola-Jones from several weeks to several hours. Unlike other approaches in the literature tested but not designed to operate in the thermal band, our method yields a significantly high detection accuracy that reaches ~91.5%. Further analysis on the profile face image dataset collected in the thermal-band yielded that: (a) photometric normalization can improve detection rate when applied only to falsely detected images. (b) the trade-off between detection accuracy and image resolution, where one third of the original resolution (~20% of original computational) can retain the same detection accuracy acquired using the original resolution.

To the best of our knowledge this is the first time that this problem of human ear segmentation in the thermal band is being investigated in the open literature.

8354-37, Session 8

Accurate thermal imaging of low-emissivity surfaces using approximate blackbody cavities

F. Turner, S. Metcalfe, J. Willmott, P. Drögmöller, Land Instruments International (United Kingdom)

Remote temperature sensing and thermal imaging can be invaluable tools for process control and optimisation. Their utilisation is limited within the metal processing industries, however, as bright metal surfaces are highly reflective, with low emissivity that can vary critically with oxide thickness and alloy composition. Any infrared temperature measurement is vulnerable to background reflection and limited to the uncertainty in the emissivity.

An enclosure or cavity made of any material offers an approximation to blackbody radiation, as both emitted and reflected radiation is collected within the cavity, and background radiation is excluded by the geometry.

By exploiting natural cavities formed during processing, emissivity-independent measurements can be made.

This paper presents thermal imaging data from an aluminium rolling application. Data was gathered using Land's FTI-E imaging system. Based on an uncooled amorphous silicon array, the system provides measurement in the range 200oC to 600oC to an accuracy of ±1oC. The 320 x 240 pixels each have field of view 570:1, providing a total viewing angle of 32o by 24o. Data was processed by Land's LIPS ASPS software, which features a patented algorithm for identifying the area of true temperature measurement within the cavity. The software automatically locates the wedge as the strip is coiled, and tracks its position as the coil increases in size. Successive profile graphs are collated to form a '2D map' of the whole strip.

The results demonstrate that accurate, emissivity-independent temperature measurements can be obtained from the wedge-shaped cavity formed where the sheet aluminium joins the roll.

8354-38, Session 8

Microscale thermal analysis with cooled and uncooled infrared cameras

J. Morikawa, Tokyo Institute of Technology (Japan); E. Hayakawa, ai-Phase Co., Ltd. (Japan); T. Hashimoto, Tokyo Institute of Technology (Japan)

Uncooled micro-bolometer of 17 micron pitch has been successfully applied to the micro-scale thermal analysis with a newly designed optics, the emissivity corrected procedure, and the quasi - accelerated time - frame capturing method. The spatial resolution 11 micron in a good balance of MTF and N.A. has been achieved for VOx FPA. It enables to visualize the exothermic latent heat of freezing biological cells at a minus temperature. The emissivity corrected micro-scale thermal imaging using a real time direct impose-signal system is examined with VOx FPA and the results are compared with the results using InSb cooled IR cameras.

In order to calibrate the intensity of all pixels in FPA into temperature, the measured temperature data is directly imposed to the intensity signal. The measuring instrument, including the signal imposing system, is designed as follows:

A: Signal (NTSC, LVDS) capturing part,

B: Superimposer of video signal,

C: Timing trigger generator,

D: Synchronous IR camera with InSb and VOx FPA sensors,

E: High-precision / high-speed temperature controller,

F: Actuator and laser drive

G: Stage scanners.

A handy size design is realized when VOx FPA is applied.

The laser drive for generating a modulated spot heating with 630 nm diode laser and the xy positioning actuator are triggered with a timing signal synchronous to the NTSC image capturing. The quasi-accelerated modulated thermal wave is analyzed based on the computational phase lock-in system for the temporal evolution extracted from the sequence of infrared image.

8354-39, Session 9

On the thermal-offset in NIR hyperspectral cameras

F. I. Parra, J. E. Pezoa, P. F. Meza, S. N. Torres, Univ. de Concepción (Chile)

Our group has developed a Planck physics-based model for near infrared (NIR) hyperspectral cameras. During the development of such model, experiments conducted using a NIR hyperspectral camera have shown that, when thermal radiation is used as the camera input and no illumination is present, the output exhibits an offset which happens to be thermally dependent, yet independent of the wavelengths in such band.

In this work the effect of the incident temperature on the amount of offset present in the output of NIR hyperspectral cameras has been experimentally studied and introduced in our previous model for NIR hyperspectral cameras, which regarded the offset as a constant.

The experimental study has been conducted using a NIR hyperspectral camera in the range of 900 to 1700 [nm] and a controlled illumination set-up, while different temperatures incident to the camera have been controlled by means of black-body radiator sources. The thermal-dependent offset will be modeled phenomenologically from experimental data. Initial results have shown a non-linear dependence between the offset and the temperature. This thermal-offset dependence can be used to generate new NIR hyperspectral models, new non-linear calibration procedures, and establish a basis for the study of time dependent variations of the NIR thermal-offset.

8354-40, Session 9

Variable filter array spectrometer of VPD PbSe

R. Linares-Herrero, G. Vergara, T. Montojo, R. Gutierrez, C. Fernandez-Montojo, A. Baldasano, New Infrared Technologies, Ltd. (Spain)

MWIR spectroscopy shows a large potential in the current IR devices market, due to its multiple applications (gas detection, chemical analysis, industrial monitoring, combustion and flame characterization, etc) and its outstanding performance (good sensitivity, NDT method, velocity of response, among others), opening this technique to very diverse fields of application, such as industrial monitoring and control, agriculture, medicine and environmental monitoring.

However, even though a big interest on MWIR spectroscopy technique has been present in the last years, two major barriers have held it back from its widespread and use outside the laboratory: the complexity and delicateness of some popular techniques such as Fourier-transform IR (FT-IR) spectrometers, and the lack of affordable specific key elements such a MWIR light sources and low cost detectors. Recent developments in electrooptical components are helping to overcome these drawbacks. The need for simpler solutions for analytical measurements has prompted the development of better and more affordable uncooled MWIR detectors, electronics and optics.

In this paper a new MWIR spectrometry device is presented. Based on linear arrays of different geometries (64, 128 and 256 elements), NIT has developed a MWIR Variable Filter Array Spectrometer (VFAS). This compact device, with no moving parts, based on a rugged and affordable detector, is suitable to be used in applications which demand high sensitivity, good spectral discrimination, reliability and compactness, and where an alternative to the traditional scanning instrument is desired. Some measurements carried out for several industries will be also presented.

8354-42, Session 9

Radiance and atmosphere propagation-based method for the target range estimation

H. Cho, J. Chun, KAIST (Korea, Republic of)

In the last several decades, the target range estimation algorithms based on many kind of active radar and sonar system have been researched. Although these algorithms show satisfactory results, the performance of such active sensor devices is degraded tremendously by jamming signal from the enemy. Unlike the radar and active sonar systems, the passive IR sensor is robust against electromagnetic jamming.

This paper proposes a new estimation method for the distance between the target and the sensor. Passive IR sensors measures radiance at different wavelength and this method shows robustness

against electromagnetic jamming. The measured target radiance of each wavelength from the sensor depends on the emissive properties of target material and is attenuated by various factors, in particular the distance between the sensor and the target and atmosphere environment. MODTRAN is a tool that models atmospheric propagation of electromagnetic radiation for wavelengths extending from the thermal infrared through the visible and into the ultraviolet. Based on the result from MODTRAN and measured radiance, the target range is estimated.

In order to verify the simulated results, an experiment to measure target radiance has undergone using the mid wave infrared camera, FLIR SC7600(MWIR camera) of which temperature resolution is 0.02°C in the working range of -20°C to +100°C. Comparing the result from the simulation and the experiment, the two values of estimated target range are close.

8354-43, Session 9

Spatial concentration distribution model for short-range continuous gas leakage of small amount

M. Wang, L. Wang, J. Li, Y. Long, Y. Gao, Beijing Institute of Technology (China)

Passive infrared gas imaging systems have been utilized in the equipment leak detection and repair in chemical manufacturers and petroleum refineries. The detection performance mainly relates to the sensitivity of infrared detector, optical depth of gas, atmospheric transmission, wind speed, and so on. Based on our knowledge, the spatial concentration distribution of continuously leaking gas plays an important part in leak detection. Several computational model of gas diffusion were proposed by researchers, such as Gaussian model, BM model, Sutton model and FEM3 model. But these models focus on calculating a large scale gas concentration distribution for a great amount of gas leaks above over 100-meter height, and not applicable to assess detection limit of a gas imaging system in short range. In this paper, a wind tunnel experiment is designed. Under different leaking rate and wind speed, concentration in different spatial positions is measured simultaneously by multiple gas detectors. Through analyzing the experimental data, the two parameters $\sigma y(x)$ and σz (x) that determine the plume dispersion in Gaussian model are adjusted to produce the best curve fit to the gas concentration data. Then a concentration distribution model for small mount gas leakage in short range is established. Various gases, CO, CO_2, SF_6 and ethane are used to testify this model.

8354-44, Session 9

Gas imaging detectivity model combining leakeage spot size and range

J. Li, L. Wang, M. Wang, Y. Gao, T. Xu, Beijing Institute of Technology (China)

As to visualize the leaking gas cloud which is not visible to the naked eyes, three categories of techniques have emerged, Backscatter Absorption Gas Imaging, Passive Thermal Imaging, and Imaging Spectrometer. Among these systems, Signal to Noise Ratio (SNR) is generally used to deduce gas leakage detection limit and leads to several performance evaluation parameters, such as Noise-Equivalent Spectral Radiance and Noise-Equivalent Concentration-Path Length. However, in most cases, measuring the SNR accurately is not accessible and usually needs auxiliary instruments. Therefore, we focus on researching a gas leakage detection model according to the general parameter of a thermal imager, Noise Equivalent Temperature Difference (NETD). Firstly, the Gas Equivalent Temperature Difference (GETD) is obtained by calculating the attenuated radiation of the On-plume path and that of the Off-plume path respectively. A simplified form of GETD was derived by our previous paper, assuming that the work range was short and the affection of atmospheric transmission was omitted. But in this paper, more factors are considered to establish a more realistic and accurate detectivity model. The radiation of the gas cloud and the attenuation of the atmosphere are taken into account as well as the size of the leakage spot which inevitably affects the concentration path length. Secondly, the NETD and the GETD are compared to determine the detection capability. At last, an experiment is designed to verify the accuracy and reliability of this model on the basis of the gas cloud concentration cone distribution model.

8354-41, Poster Session

A method for infrared video mosaic based on SURF

Y. Chen, National Univ. of Defense Technology (China) and Graz Univ. of Technology (Austria); Y. Feng, Y. Cao, National Univ. of Defense Technology (China)

Because of the drawback of spatial resolution lying in infrared imaging sensor, hence it appears intuitive that video mosaic is needed in some situations demanding more wide field of view. So the technology for infrared video mosaic is widely applied in remote sensing, military reconnoitering, and monitoring. The key procedure of video mosaic is image registration. Generally speaking, the infrared image registration methods can be lumped into three categories. One category is the methods based on gray information like template matching; another is based on transform domain such as Fourier transform; and the third uses image local invariant features, for instance, SIFT (Scale-invariant feature transform) and SURF (Speeded Up Robust Features). Unfortunately, the two former have some disadvantages at registration accuracy, applicability or computational cost. The last one is attractive for its performance of practice, and real-time, which has high applicability in actual application. Literature [10-11] presented a successful method for infrared video mosaic utilizing SIFT feature. But using SIFT feature will take too much time implement the mosaic algorithm. In this case, SURF which has good computation characteristic, can make an excellent alternative to the SIFT approaches.

This chapter focuses on presenting a fast and effective algorithm based on SURF features for infrared video mosaic. The algorithm firstly utilizes SURF method with strong robustness and superior computational performance to extract features and complete feature matching. Secondly, a RANSAC technique is applied to suppress matching errors, and to estimate the homography between adjacent frames. Finally, an improved global registration strategy is adopted to compute the transformations between video frames and the panorama by a least-square solution, and panorama from infrared video is obtained using the transformation parameters. This global registration method is distinctly different from conventional technique, which obtains the transformation between video frame and the panorama by means of multiplying transformation matrixes of adjacent frames. A mosaic test was carried out employing infrared video sequence captured by a HJRG-001 infrared thermal imager, and experimental results indicate that the proposed method is fast and effective and has strong robustness even for infrared images with high noise, low contrast and few features. This method has high potential for practical applications.

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SPIE Defense, Security+Sensing

8355-01, Session 1

Deriving field-performance metrics from laboratory test measurements in real time

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Santa Barbara Infrared, Inc.(SBIR), working with Night Vision and Electronic Sensors Directorate (NVESD), has investigated combining the IRWindows 4 automated testing platform with the Night Vision Integrated Performance Model (NV-IPM) to change the way laboratory specifications of electro-optical equipment are defined. As a practical matter, testing and modeling have been separate activities used in the design and validation of electro-optical systems. Performance models (such as NV-IPM) are used to predict the field performance of a system design and generate laboratory testing specifications. Because laboratory testing uses metrics that are not directly and easily translatable into the metrics used to define field performance, manufacturing and testing these systems in a production laboratory can easily become isolated from the desired field performance. By providing a tool that directly converts laboratory measurements into field performance metrics, the repair and calibration of a system under test can be directly optimized for field performance. In addition, this simplifies system specifications, eliminating the need to translate field performance specifications into isolated electro-optical metrics. When this capability is combined with field transportable test hardware (such as the SBIR Common Module system) and used on deployed hardware, real time field performance of the available electro-optical systems can be provided to the mission planner.

8355-02, Session 1

Spectral responsivity calibrations of two pyroelectric radiometers using three different methods

J. Zeng, G. P. Eppeldauer, L. M. Hanssen, S. G. Kaplan, B. H. Wilthan, V. B. Podobedov, National Institute of Standards and Technology (United States)

Spectral responsivity calibrations of two different type pyroelectric radiometers have been made in infrared region up to 14 µm in power mode using three different calibration facilities at NIST. One pyroelectric radiometer is a temperature controlled low-NEP single-element pyroelectric radiometer with an active area of 5 mm in diameter; the other is a same type pyroleletric radiometer with a dome-input optics, which is designed to increase absorptance and to minimize spectral structures for a flat spectral responsivity. Several calibration facilities at NIST were used to conduct direct and indirect calibrations with high accuracy in spectral regime and absolute scales depending on geometry of radiometers. We report the calibration results for the single-element pyroelectric radiometer using a new infrared Spectral Comparator Facility (IR SCF) for direct calibration and a combination method of FTIR and tie-point as an indirect approach. For the dome-input pyroelectric radiometer, the results from another direct calibration method using circular variable filter (CVF) and the IR SCF are presented as well. The inter-comparison of different calibration methods enables us to improve calibration accuracy and lower uncertainty among facilities. For both radiometers, the consistent results of spectral responsivity have been obtained by different methods from 1.6 µm to 14 µm with the uncertainty between 1 % and 2 % (k=2). Relevant characterization results such as spatial uniformity, linearity, frequency dependence, are shown. Validation of calibration, uncertainty sources, and improvement for each method will also be discussed.

8355-03, Session 1

Using GStreamer to perform real-time MRTD measurements on thermal imaging systems

S. D. Burks, J. M. Doe, J. D. Fanning, J. P. Reynolds, K. Garner, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

The GStreamer architecture allows for simple modularized processing. Individual GStreamer element have been developed that allow for control, measurement, and ramping of a blackbody, for capturing continuous imagery from a sensor, for segmenting out a MRTD target, for applying a blur equivalent to that of a human eye and a display, and for thresholding a processed target contrast for “calling” it. A discussion of each of the components will be followed by an analysis of its performance relative to that of human observers.

8355-04, Session 1

PV-MCT working standard radiometer

G. P. Eppeldauer, J. Zeng, V. B. Podobedov, National Institute of Standards and Technology (United States)

Sensitive infrared working-standard detectors with large area are needed to extend the signal dynamic range of the NIST pyroelectric transfer-standard detectors used for IR spectral responsivity calibrations. The noise equivalent power of the pyroelectric transfer-standards is about 8 nW/Hz^½, equal to a D*= 5.5 x 10^7 cm Hz^1/2/W. A large-area photovoltaic HgCdTe (PV-MCT) detector was custom made for the 2.5 to 11 micrometer wavelength range. Using a 4-stage thermoelectric cooler, the D* was increased to be about two orders of magnitude higher than that of the pyroelectric transfer-standards. The large detector area was produced with multiple p-n junctions. The horizontally stacked junctions resulted in a 4 x 4 mm active area needed for radiant power measurements where the detector in underfilled by the incident radiation. However, the periodical, multiple-junction structure of 20 micrometer with a fill factor of 0.6 produced a spatial non-uniformity in the detector response. The PV-MCT radiometer was characterized for spatial non-uniformity of response at different wavelengths using different incident beam sizes to evaluate how to perform low responsivity uncertainties. The frequency dependent response, angular response, linearity, noise performance, and spectral power responsivity were measured and evaluated. An uncertainty budget for spectral power responsivity measurements was determined.

8355-05, Session 1

Advanced techniques for noise suppression in MTF measurements

D. P. Haefner, S. D. Burks, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

The modulation transfer function (MTF) measurement is critical for understanding the performance of an EOIR system. Unfortunately, due to both spatially correlated and spatially un-correlated noise sources, the performance of the MTF measurement (specifically near the cutoff) can be severely degraded. One proposed solution is to apply a filter to the edge response function in order to suppress row and column noise. Although this technique shows promise for correlated noise, un-correlated noise continues to degrade performance. This paper presents a new technique that reduces the effects of both correlated

and un-correlated noise. This new technique creates a super resolved edge spread function from all possible non-redundant samplings of the measurement. A spatial average of the edge spread function is accomplished by applying the appropriate spatial shift through a phase correction. We also show how this technique may be applied for a generalized two-dimensional tilted-edge calculation.

8355-06, Session 1

Laser speckle MTF processing and test development for VIS and IR sensors

P. P. K. Lee, ITT Corp. Geospatial Systems (United States); C. W. McMurtry, E. J. Tan, J. L. Pipher, M. F. Bocko, Univ. of Rochester (United States); J. D. Newman, ITT Corp. Geospatial Systems (United States)

Using band-limited laser speckle to measure the Modulation Transfer Function (MTF) of an image sensor offers simplified procedure and inexpensive laboratory set up compared with the traditional method of using a knife edge on the sensor imaging plane. This technique has been previously demonstrated by Borman et al on devices in the visible range. We have extended the procedure to short-wave and mid-wave infrared (IR) sensor at 1.55 and 3.4 microns. Similar measurements were also made at 532 nanometer on commercial visible (VIS) sensors. The experiments show that the laser speckle method to be accurate when compared to theoretical and knife-edge measurements for data below Nyquist. The measured MTF data support optical system design and image quality modeling for both VIS and IR sensing applications.

8355-07, Session 2

Precise economical lens calibration and measurement techniques for VIS, NIR, and LWIR optical systems

S. D. Fantone, D. Orband, Optikos Corp. (United States)

Lens calibration and measurement techniques are presented using a video based (US Patent 5,661,816), dual band MTF test station that provides real time MTF testing of both the visible and LWIR wavelength for the optics used in IR optical systems, visible systems and EO imaging systems. The compact, economical test station is intended to be easily operated by a technician. It measures MTF, focal length, astigmatism, field curvature, blur spot size, distortion, and other metrics of system performance. The system enables spectral simulation for testing optics under actual broad band multi-spectral conditions to replicate a unit under test's performance over actual environmental conditions.

The test station's unique hardware arrangement permits users to perform trouble-free waveband conversions for the VIS/NIR and LWIR regions through a thoroughly engineered re-configuration procedure. Detailed descriptions for this conversion procedure are provided.

The compact unit is designed to facilitate an all-mirror reflective collimator to be installed. By changing to a reflective collimator and replacing the image analyzer, the targets and the source module, operators are able to readily test Visible, NIR and LWIR optics.

Specific optical elements will be discussed with the associated test results and techniques. We will also describe system repeatability to reveal the robustness of the measurement platform. Accuracies will be detailed and linked to key design aspects of this test equipment.

8355-08, Session 2

Advanced trend removal in 3D noise calculation

S. D. Burks, H. Nguyen, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

While it is now common practice to use a trend removal to eliminate low frequency fixed pattern noise in thermal imaging systems, there is still some disagreement as to whether one means of trend removal is better than another and whether or not the strength of the trend removal should be limited. The different methods for trend removal will be presented as well as an analysis of the calculated noise as a function of their strengths will be presented for various thermal imaging systems. In addition, trend removals were originally put in place in order to suppress the low-frequency component of the Sigma VH term. It is now prudent to perform a trend removal at an intermediate noise calculation step in order to suppress the low frequency component of both the Sigma V and Sigma H components. A discussion of the ramifications of this change in measurement will be included for thermal modeling considerations.

8355-09, Session 2

Modulation transfer function measurement of a 640×480 microbolometer focal plane array with a pixel pitch of 17 µm

G. Druart, F. de la Barrière, ONERA (France); J. Taboury, Institut d'Optique Graduate School (France); N. Guérineau, ONERA (France); H. Sauer, Institut d'Optique Graduate School (France); A. A. Crastes, ULIS (France)

Today, both military and civilian applications require miniaturized and cheap optical systems. One way to achieve this trend consists in decreasing the pixel pitch of focal plane arrays.

In order to evaluate the performance of the overall optical systems, it is necessary to measure the modulation transfer function (MTF) of these pixels. However, small pixels lead to higher cut-off frequencies and therefore, original MTF measurements that are able to extract frequencies up to these high cut-off frequencies, are needed.

In this paper, we will present a way to extract 1D MTF at high frequencies by projecting fringes on the FPA. The device uses a Lloyd mirror placed near and perpendicular to the focal plane array. Consequently, an interference pattern of fringes can be projected on the detector. By varying the angle of incidence of the light beam, we can tune the period of the interference fringes and, thus, explore a wide range of spatial frequencies, and mainly around the cut-off frequency which is one of the most interesting area.

Illustration of this method will be applied to a 640×480 wideband microbolometer focal plane array with a pixel pitch of 17µm in two spectral regions: MWIR and LWIR. A discussion about these two spectral results will be lead.

8355-10, Session 2

On-axis and off-axis characterization of MWIR and LWIR imaging systems using quadri-wave interferometry

S. Velghe, D. Brahmi, W. Boucher, B. Wattellier, PHASICS S.A. (France)

The development of new infrared optical components, such as high numerical aperture objectives or the use of aspheres to gain weight has to be supported by new characterization means. Though MTF remains a standard for objective qualification, it does not quantitatively diagnose possible defects of the analyzed objective (misalignment, inadequate asphеrization, ...). Moreover, the objectives alignment procedures on standard MTF test bench are complex and time consuming. In this paper, we present an innovative technique that overcomes these limitations.

Our technique is based on Quadri-Wave Lateral Shearing Interferometry (QWLSI), an innovative wave front sensing technique. The device is very compact as it only uses a specific diffractive grating placed in front of a

FPA. The bench is composed of a source assembly, the objective and the wave front sensor placed in the divergent beam (at a few millimeters after the focal spot). The aberration function is then deduced from the measured wave front.

For off-axis analysis, we illuminate the objective with a tilted beam. The sensor is then simply moved to follow the beam. With this method, it is possible to analyze the evolution of aberrations (such as astigmatism or coma) for different field values and field curvature (with the defocus term). A complete characterization for several field points is possible within a few minutes.

In this paper, we will present the QWLSI technology and its application in the MWIR and LWIR bands for on and off-axis metrology. Experimental analysis and comparison to theoretical values of optical components will be discussed.

8355-44, Session 2

Rapid electro-optical (EO) TPS development in a military environment

J. McKechnie, B. Nehring, A. Irwin, B. Lunt, S. W. McHugh, Santa Barbara Infrared, Inc. (United States)

Santa Barbara Infrared, Inc. has deployed IRWindows as an Electro-Optical test development and execution environment for military Test Program Sets (TPS). Advantages of TPS development for EO systems in the IRWindows environment are seen compared to the TPS development in ATLAS. The advantages of the IRWindows environment are:

1. Faster learning curve (graphical user interface is easier than test line interface)

2. Faster TPS development time (real time changes and asset control interface allows for faster development)

3. Asset control panel allows user to control assets real time and monitor all asset functions during development

4. Unit Under Test (UUT) image viewer allows user to set test parameters like Region of Interest more easily and more precisely

5. Continuous mode tests (like MTF allows user to real time adjustments)

6. Open architecture for test modifications

This paper will outline the details of how these advantages are utilized and how not only development time is decreased but also how test execution time can be minimized making traditionally long TPS run times on EO systems more efficient.

8355-12, Session 3

Atmospheric effects on target acquisition

N. S. Kopeika, A. Zilberman, Y. Yitzhaky, E. Golbraikh, Ben-Gurion Univ. of the Negev (Israel)

Imaging systems have advanced significantly in the last decades in terms of low noise and better resolution. While imaging hardware resolution can be limited by collection aperture size or by the camera modulation transfer function (MTF), it is the atmosphere that usually limits image quality for long range imaging. The main atmospheric distortions are caused by optical turbulence, absorption, and scattering by particulates in the atmosphere.

The effect of the turbulent medium over long/short exposures is to produce image blur and wavefront tilt that causes image shifts at the image plane. This blur limits the number of line pairs in the target’s image and thus affects the ability to acquire targets. The observer appears to be able to ignore large-scale distortions while small-scale distortions blur the image and degrade resolution. Resolution degradations due to turbulence are included in current performance models by use of an atmospheric modulation transfer function.

Turbulence distortion effects are characterized by both short and long exposure MTFs. In addition to turbulence, there are scattering and absorption effects produced by molecules and aerosols in the atmosphere. These cause both attenuation and additional image blur according to the atmospheric aerosol MTF. The absorption can have significant effect on target acquisition in the IR.

In the present paper, a brief overview and discussion of atmospheric effects on target acquisition in the IR is given.

8355-13, Session 3

Improved motion estimation for restoring turbulence-distorted video

C. M. Zwart, Arizona State Univ. (United States); R. J. Pracht, D. H. Frakes, 4-D Imaging, Inc. (United States)

Artificial displacement (the apparent motion of stationary objects) is one important component of atmospheric turbulence distortion, which has led many researchers to propose motion compensation as a solution. Defining a sufficiently dense set of motion estimates for successful restoration is challenging, particularly for time sensitive applications. We introduce a new control grid implementation of optical flow that allows for rapid and effective analytical solutions to the motion estimation problem. Our results also demonstrate the effectiveness of using the resulting motion field for removing artificial displacements in turbulence-distorted videos.

8355-14, Session 3

Impact of atmospheric aerosols on long-range infrared image quality

D. A. LeMaster, M. T. Eismann, Air Force Research Lab. (United States)

Image quality of long range infrared imaging systems can be severely limited by atmospheric impacts such as absorption, scattering, and turbulence. Atmospheric aerosols influence image quality through signal attenuation, contrast reduction and spatial blurring, although the aerosol blurring effect is often ignored in system models. The validity of this assumption is tested in this paper for the case of high altitude long range infrared imaging. This is performed by comparing the image quality impacts for a baseline long range system design from atmospheric absorption, scattering, and turbulence using the Generalized Image Quality Equation (GIQE). A modulation transfer function (MTF) is developed to accommodate aerosol impacts for several environmental conditions. The results of this study provide insights into the fundamental limitations of long range imaging for different spectral regions, and where sensor and processing technology may provide a benefit.

8355-15, Session 3

Fried deconvolution

J. Gilles, S. Osher, Univ. of California, Los Angeles (United States)

In this paper we present a new approach to deblur the effect of atmosphere in the case of long range imaging even in the case of turbulence.

This method is based on an analytical formulation, the Fried kernel, of the atmosphere modulation transfer function (MTF) and an efficient deconvolution algorithm.

The deconvolution algorithm uses the sparsity assumption of the coefficients for some framelet expansion of the reconstructed image. This permits to have a regularized image with its edges preserved. We propose two approaches regarding the knowledge of the parameters.

In the first part of this work, we assume that all parameters are known. Then we show the efficiency of the Fried kernel to improve long range images and we study the influence of the different parameters.

In the second part, we deal with the refractive index structure (Cn2). It is an important parameter which represent the turbulence level of the atmosphere, it requires specific and difficult acquisitions to be known. We propose a method based on a total variation criteria to find a good estimation of this parameter from the input blurred image. We generate the deconvolved images associated to a regular sampled set values of Cn2. Then we compute their corresponding total variation and choose the final Cn2 from the maximum of a polynomial interpolation of the total variation curve.

The final algorithms are very easy to implement and show very good results on both simulated blur and real images from the NATO SET40 Dataset.

8355-16, Session 3

Turbulence stabilization

Y. Mao, Univ. of Minnesota (United States); J. Gilles, Univ. of California, Los Angeles (United States)

Long range imaging systems are inevitably confronted to the effect of atmospheric turbulence. According to the work of Frakes, the corresponding effects in the image plane can be modeled as a composition of some geometric distortions (usually called image dancing) and some blurs. In this paper, we focus on the geometric distortions problem. We propose an effective algorithm devoted to correct those deformations from very few original acquired frames. Our approach combines two main blocks. First, an optical flow algorithm which aims to model the deformation field applied on a reference. The second block is a kind of regularized method which permits us to retrieve a restored image by minimization. The whole method can be implemented easily and efficiently by using the Bregman iterations nowadays widely used in the literature for its good properties in term of convergence and speed. We propose to evaluate performances of different kind of regularizations such the classic total variation, the nonlocal total variation, or a framelet sparsity constraint. We also do some experiments with two different optical flow methods: the classic Lucas-Kanade algorithm, which is fast but less precise, and the Black-Anandan algorithm, which is slower but provides a very precise deformation field. The final choice will depend on practical issues such computing time and reconstruction efficiency. We propose different tests based on real images taken from the NATO SET40 and the NVESD Datasets and we will see that the algorithm performs well by using only few inputs frames (typically five to ten are enough).

8355-17, Session 3

Turbulence mitigation of short exposure image data using motion detection and background segmentation

C. S. Huebner, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Many remote sensing applications are concerned with observing objects over long horizontal paths and often the atmosphere between observer and object is quite turbulent, especially in arid or semi-arid regions. Depending on the degree of turbulence, atmospheric turbulence can cause quite severe image degradation, the foremost effects being temporal and spatial blurring. And since the observed objects are not necessarily stationary, motion blurring can also factor in the degradation process. At present, the majority of these image processing methods aim exclusively at the restoration of static scenes. Since there is a growing interest in furthering turbulence mitigation to include moving objects as well, the approach in this paper is to employ standard motion detection algorithms, e. g. block-matching, in order to separate directed object motion from undirected movement due to turbulence. This way, a segmentation of static scene elements and moving objects is possible, provided that the object movement exceeds the apparent motion caused by the atmospheric turbulence, and image restoration can be carried out for static and moving elements, independently. Local image stacking is used to help correct for directed object motion, thus effectively reducing motion blur created by averaging and improving the overall restoration result.

8355-18, Session 4

Short-exposure passive imaging through path-varying convective boundary layer turbulence

D. H. Tofsted, U.S. Army Research Lab. (United States)

As is well known, the atmospheric turbulence modulation transfer function (ATMTF) depends on the turbulent coherence diameter evaluated via an integration over the optical path. A recent study showed the system aperture diameter also influences the phase structure function that modifies the form of the short-exposure ATMTF.

In this paper, the influence of path-varying turbulence is studied for this new ATMTF within the context of the daytime convective boundary layer atmosphere in which turbulence decreases as a function of height above the surface. To illustrate path--varying turbulence effects, two characteristic path geometries have been parameterized: slant path propagation above flat terrain for objects and observers are possibly different heights, and propagation across a valley with objects and observers at equal heights.

Results show that the new ATMTF retains its mathematical form, but that turbulence strength variations produce variations in two parameters used in the ATMTF model. These parameters can be adjusted through specific multiplicative functions for the cases studied, or using integral relations for more complicated terrain profiles. In an analysis section, comparison of the new and original models' predicted effective bandwidths show variations of 10--60 percent for the path geometries studied.

8355-19, Session 4

An efficient turbulence simulation algorithm

A. L. Robinson, J. Smith, A. Sanders, The Univ. of Memphis (United States)

Turbulence mitigation techniques require input data representing a wide variety of turbulent atmospheric and weather conditions in order to produce robust results and wider ranges of applicability. In the past this has implied the need for numerous pieces of data collection equipment to account for multiple frequency bands and various system configurations. However, recent advancements in turbulence simulation techniques have resulted in viable options to real-time data collection that provide various levels of simulation accuracy. This treatment will detail the development and implementation of an extension to the second order statistical model presented by Repasi and others. The Repasi model is extended to include the effects of various wavelengths, optical configurations, and short exposure imaging on angle of arrival fluctuation statistics. The result of the development is an atmospheric turbulence simulation technique that is physics-based but less computationally intensive than phase-based or deflector screen approaches. The model captures the major turbulence effects required for algorithm development for large classes of mitigation techniques. In these cases the statistical approach detailed in this paper provides the user with an opportunity to obtain a better trade-off between accuracy and simulation run-time. The mathematical development and reasoning behind the changes to the previous statistical model will be presented and sample imagery produced by the extended technique will be included.

8355-20, Session 4

Energy conservation: a forgotten feature property of the turbulent point spread function

M. I. Charnotskii, National Oceanic and Atmospheric Administration (United States)

Energy conservation is an essential feature of the optical waves propagating through refractive turbulence. It was well understood for almost 30 years, that energy conservation has a very important consequence for the fluctuations in the images of the incoherent objects observed through turbulence. Namely the image of the uniformly illuminated areas of the object does not scintillate. As a consequence the low-contrast parts of the scene exhibit weak fluctuation even for very strong turbulence, and vice versa scintillation near the sharp edges is strong even for the weak turbulence. Energy conservation property of the turbulent PSF is essential for modeling of the turbulent image distortions, both for the development of the image processing techniques and for simulations of the turbulent imaging. However it is totally neglected in the current literature on the turbulent imaging theory and modeling.

We discuss the relations between the energy conservation and anisoplanatism, and show that energy conservation links together the image plane and the object plane PSF arguments. Our analysis also reveals that the only isoplanatic authentic turbulent PSF that is compliant with energy conservation corresponds to the thin aperture plane phase screen model of turbulence. This implies that for the near-the-ground imaging, and even for the astronomical-type imaging under strong turbulence conditions the turbulent PSF has to be modeled as a random function of four arguments with deterministic constraints.

We show some practical ways how the fundamental constrains on the turbulent PSF: nonnegative values, finite bandwidth and energy conservation can be complied with in practical generation of turbulent PSF.

8355-21, Session 4

Long-term measurements of atmospheric point-spread functions over littoral waters as determined by atmospheric turbulence

A. N. de Jong, TNO Defence, Security and Safety (Netherlands)

During the FATMOSE trial, held over the False Bay (South Africa) from November 2009 until October 2010, day and night (24/7) high resolution images were collected of point sources at a range of 15.7 km. Simultaneously data were collected on atmospheric parameters, as relevant for the turbulence conditions: air- and sea temperature, windspeed, relative humidity and the structure parameter for refractive index: Cn2. The data provide statistics on the magnitude of the mean value and the variation of the atmospheric point spread function (and thus the modulation transfer function) during series of consecutive frames. This information is of great importance for the user of optical sensors in related operational areas and for the developers of image processing algorithms. The high spatial resolution data have been compared with simultaneously obtained scintillation data, collected with the same sensor and with a high speed radiometer. The data are also compared with predictions based upon directly measured scintillometer data and with Monin-Obukhov based Cn2 data, obtained from the EOSTAR sensor performance prediction tool, developed at TNO.

8355-22, Session 4

Hyperspectral image turbulence measurements of the atmosphere

S. E. Lane, L. West, G. G. Gimmestad, E. M. Burdette, Georgia Tech Research Institute (United States); W. Smith, Sr., Hampton Univ. (United States)

The real-time detection of atmospheric turbulence is of great interest due to the applicability to aviation safety. A Forward Looking Interferometer (FLI) sensor has the potential to be used as a means of detecting aviation hazards in flight, giving the flight crew time to react. One of these hazards is mountain wave turbulence. The results from a data acquisition activity at the Mountain Research Station near Boulder, Colorado, will be presented here. This site in the Rocky Mountains experiences mountain waves and mountain wave turbulence in the fall and winter that affects flights into Denver International Airport. This data collection activity, scheduled for November 2011 weather permitting, will utilize a long wave infrared (LWIR) Telops Hyper-Cam and a Designs and Prototypes TurboFT spectrometer as a means of studying the feasibility of using a FLI sensor for the detection of turbulent events. Each sensor provides unique information about the events; the Hyper-Cam collects LWIR hyperspectral image data of the scene, while the TurboFT has the capability to collect approximately 100 spectra per second in the 2-16 micron region. Both sensors have on-board blackbodies, which allow for calibrated radiance in the field. The two sensors will be co-located on a custom built mount which will allow bore-sighting of the sensors. The hyperspectral datacubes from the Hyper-Cam will be studied with standard anomaly detection algorithms to determine if an event can be identified in the data. These data will then be compared with TurboFT data, which is collected at a much higher time resolution and broader spectrum.

8355-23, Session 5

Infrared detector size: how low should you go?

R. G. Driggers, U.S. Naval Research Lab. (United States); R. H. Vollmerhausen, Univ. of Delaware (United States); J. Reynolds, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States); G. C. Holst, Consultant (United States)

In the past five years, significant progress has been accomplished in the reduction of infrared detector pitch and detector size. Recently, longwave infrared detectors in limited quantities have been fabricated with a detector pitch of 5 micrometers. Detectors with 12 micrometer pitch are now becoming standard in both the midwave infrared (MWIR) and longwave infrared (LWIR) sensors. Persistent surveillance systems are pursuing 10 micrometer detector pitch in large format arrays.
The fundamental question that most system designers and detector developers desire an answer to is: “how small can you produce an infrared detector and still provide value in performance?” If a system is mostly diffraction-limited, then developing a smaller detector is of limited benefit. If a detector is so small that it does not collect enough photons to produce a good image, then a smaller detector is not much benefit. Resolution and signal-to-noise are the primary characteristics of an imaging system that contribute to targeting, pilotage, search, and other human warfighting task performance. In this paper, we investigate the task of target discrimination range performance as a function of detector size/pitch. Results for LWIR and MWIR detectors are provided and depend on a large number of assumptions that are reasonable.

8355-25, Session 6

Implementation of intensity ratio change and LOS rate change algorithms for imaging infrared trackers

C. R. Viau, Tactical Technologies Inc. (Canada)

The use of the Intensity Ratio Change (IRC) and Line-of-sight (LOS) Rate Change (LRC) concepts have previously been documented in the open-literature as techniques used by non-imaging IR seekers to reject expendable infrared (IR) countermeasures. The purpose of this study is to

determine if the IRC and LRC concepts can be ported and implemented in an imaging seeker as a form of counter-countermeasure (CCM) with the underlying goal of obtaining a better understanding of how expendable countermeasures can be used to defeat the latest generation of IR seekers.

This report reviews the IRC and LRC discrimination techniques used by non-imaging seekers and implements these concepts in a generic imaging seeker model. The report discusses how the techniques are implemented, the general implementation differences between the imaging and non-imaging trackers and identifies input/output parameters of interest. The IRC and LRC algorithms and the generic seeker model are implemented in a physics-based simulation product called Tactical Engagement Simulation Software (TESS). TESS is developed in MATLAB/ Simulink environment and is a suite of RF/IR missile simulation software used to evaluate and analyze the effectiveness of countermeasures against various classes of guided threats.

The investigation evaluates the algorithm and tests their robustness by presenting the results of Monte Carlo simulation runs of surface-to-air (SAM) and air-to-air (AAM) imaging IR missiles engaging maneuvering target platforms equipped with various expendable IR countermeasures as self-protection. The report discusses how varying critical parameters such track memory time, ratio thresholds and activation delays can influence the outcome of an engagement.

8355-26, Session 6

Turbulence compensation: an overview

A. W. M. van Eekeren, K. Schutte, J. Dijk, P. B. W. Schwering, M. van Iersel, TNO Defence, Security and Safety (Netherlands)

In general long range recognition is hampered by turbulence caused by atmospheric conditions. In the past much research has been devoted to the field of turbulence compensation. One of the main advantages of turbulence compensation is that it enables visual identification over larger distances. In many military scenarios this is of crucial importance. In this paper we give an overview of several software and hardware approaches to compensate for the visual artifacts caused by turbulence. These approaches are very diverse and range from the use of adaptive optics and phase diversity to the use of deconvolution and lucky imaging. For each approach the pros and cons are given and it is indicated for which scenario this approach is useful. In more detail we describe the turbulence compensation methods TNO has developed in the last years and place them in the context of the different turbulence compensation approaches and TNO's turbulence compensation roadmap. Furthermore we look forward and indicate the upcoming challenges in the field of turbulence compensation.

8355-27, Session 6

A real-time atmospheric turbulence mitigation and superresolution solution for infrared imaging systems

D. R. Droege, L-3 Communications Cincinnati Electronics (United States); R. C. Hardie, L-3 Communications Cincinnati Electronics (United States) and Univ. of Dayton (United States); B. S. Allen, A. J. Dapore, J. C. Blevins, L-3 Communications Cincinnati Electronics (United States)

Imagery acquired with modern imaging systems is susceptible to a variety of degradations, including blur from the point spread function (PSF) of the imaging system, aliasing from undersampling, blur and warping from atmospheric turbulence, and noise. A variety of image restoration methods have been proposed that estimate an improved image by processing a sequence of these degraded images. In particular, multi-frame image restoration has proven to be a particularly powerful tool for atmospheric turbulence mitigation (TM) and super-resolution (SR). However, these degradations are rarely addressed simultaneously using a common algorithm architecture, and few TM or SR solutions are capable of performing robustly in the presence of true scene motion, such as moving dismounts. Still fewer TM or SR algorithms have found their way into practical real-time implementations. In this paper, we describe a new L-3 joint TM and SR (TMSR) real-time processing solution and demonstrate its capabilities. The system employs a recently developed versatile multi-frame joint TMSR algorithm that has been implemented using a real-time, low-power FPGA processor system. The L-3 TMSR solution can accommodate a wide spectrum of atmospheric conditions and can robustly handle moving vehicles and dismounts. This novel approach unites previous work in TM and SR and also incorporates robust moving object detection. To demonstrate the capabilities of the TMSR solution, results using field test data captured under a variety of turbulence levels, optical configurations, and applications are presented. The performance of the hardware implementation is presented, and we identify specific insertion paths into tactical sensor systems.

8355-28, Session 6

Turbulence degradation and mitigation performance for handheld weapon ID

R. L. Espinola, S. Aghera, J. Miller, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

Atmospheric turbulence can severely limit the range performance of state-of-the-art large aperture imaging sensor systems, specifically those intended for long range ground to ground target identification. Simple and cost-effective mitigation solutions which operate in real-time are desired. Software-based post-processing techniques are attractive as they lend themselves to easy implementation and integration into the back-end of existing sensor systems. Recently, various post-processing algorithms to mitigate turbulence have been developed and implemented in real-time hardware. To determine their utility in Army-relevant tactical scenarios, an assessment of the impact of the post processing on observer performance is required. In this paper, we test a set of representative turbulence mitigation algorithms on field collected data of human targets carrying various handheld objects in varying turbulence conditions. We use a controlled human perception test to assess handheld weapon identification performance before and after turbulence mitigation post-processing. In addition, novel image analysis tools are implemented to estimate turbulence strength from the scene. Results of this assessment will lead to recommendations on cost-effective turbulence mitigation strategies suitable for future sensor systems.

8355-29, Session 6

Patch-based local turbulence compensation in anisoplanatic conditions

A. W. M. van Eekeren, M. Kruithof, K. Schutte, J. Dijk, M. van Iersel, P. B. W. Schwering, TNO Defence, Security and Safety (Netherlands)

Infrared imagery over long range is hampered by atmospheric turbulence effects, leading to spatial resolutions worse than theoretically possible with a sensor system. This diminishes the recognition range. Therefore it is important to compensate visual artifacts due to atmospheric turbulence. The amount of turbulence is spatially varying due to anisoplanatic conditions while the isoplanatic angle varies with atmospheric conditions. But also the amount of turbulence varies significantly in time. In this paper a method is proposed that performs turbulence compensation using a patch-based approach. In each patch the turbulence is considered to be approximately spatially and temporally constant. Our method is based on multi-frame super-resolution, which incorporates registration, fusion and deconvolution of the data and also can increase the resolution. The main difference with traditional turbulence compensation methods is that our method uses a locally (in space and time) estimated blur in the deconvolution step. This makes our method especially suited to use under anisoplanatic conditions. In

this paper we show that the estimated blur is consistent with spot size measurements of a point source in the images. Furthermore we show that our method performs better in comparison with traditional methods.

8355-30, Session 7

High-fidelity simulations of infrared imagery with animated characters

F. Näsström, A. Persson, J. Berggren, J. Hedström, J. Allvar, M. Karlsson, Swedish Defence Research Agency (Sweden)

High fidelity simulations of IR signatures and imagery tend to be slow and do not have effective support for animation of human characters. Simplified rendering methods based on computer graphics methods can be used to overcome these limitations. This paper presents a method to combine these tools and produce simulated high fidelity IR data of animated people in terrain.

Infrared signatures for several people have been calculated using RadThermIR. To efficiently handle multiple character models, these calculations use a simplified material model for the human anatomy and clothing. Weather and temperature conditions have been set to match the fixed IR-texture for the terrain. The signatures are then applied to the animated 3D characters. They can be used together with a terrain model with a fixed infrared texture, to produce high fidelity IR imagery of moving people or crowds.

There are tools available to create and visualize skeleton based animation but it is hard to find tools that let you control the animated characters on a higher level, e.g. for crowd simulation. The HLAS, High Level Animation System, has been developed to make it easy to integrate animated sequences for different types of simulation frameworks.

An outdoor area has been measured with an airborne laser system and from these data a 3D terrain model has been created, and textured with high resolution IR data. The animated characters are placed in the 3D terrain model to simulate realistic situations.

8355-31, Session 7

Simulating the visual and infrared scene of a space-based instrument with spacecraft intrusions

M. A. Gauvin, Lambda Research (United States)

This paper details the methodology needed to completely model a space based satellite for visual and infrared imagery. This task is made difficult due to the physical size of the CAD model, the complexity needed to correctly model high pixel infrared detectors, the difficult nature of measuring infrared surfaces for scattering and the merging of multiple datasets to create a composite image. The methodology used to model this system is broken down into small steps that show how to create a successful workable CAD model that can be raytraced using commercial software. It also shows how to determine surface and material properties for use in the simulation. A detailed step by step process is undertaken to simulate the model using raytrace methods to trace the millions of rays necessary to accurately model the system using a known scene. Finally, we will discuss how to take into account the obscurations and stray light caused by external apparatus, extraneous gear and solar panels outside and inside the field of view of the instrument.

8355-32, Session 7

Infrared signature measurements with the ABB dual-band hyperspectral imager

L. M. Moreau, S. Lantagne, ABB Analytical Measurement (Canada); R. D. Bullis, Naval Air Warfare Ctr. Aircraft Div. (United States)

MRi is an imaging version of the ABB MR series Fourier-Transform spectroradiometer. This field instrument generates spectral datacubes in the MWIR and LWIR. It is designed to acquire the spectral signatures of rapidly evolving events.

The design is modular. The two output ports of the instrument can be populated with different combinations of detectors (imaging or not). For instance to measure over a broad spectral range, one output port can be equipped with a LWIR camera while the other port is equipped with a MWIR camera. No dichroics are used to split the bands, hence enhancing the sensitivity. Both ports can be equipped with cameras serving the same spectral range but set at different sensitivity levels in order to increase the measurement dynamic range and avoid saturation of bright parts of the scene while simultaneously obtaining good measurement of the faintest parts of the scene. Various telescope options are available for the input port.

Recent platform developments and field trial measurements performances will be presented.

8355-60, Session 7

Comparison of image restoration algorithms in the context of horizontal-path imaging

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We have benchmarked a number of image restoration techniques: multi-frame blind deconvolution, Ayers-Dainty-type deconvolution, principal component analysis, maximum-a-posteriori deconvolution and maximum-likelihood, wavelet-based deconvolution. The input data comes from simulations of a “slant view” observing scenario, and also from actual horizontal imaging tests over 2.5 km and 7 km paths.

We focus here on the isoplanatic imaging conditions and discuss the problem of “blind” image restoration in this relatively “easy” scenario. The PSF of the observations is extracted directly from the images or from auxiliary scintillation data. First we estimate the spatial coherence length of the atmosphere, that is, the Fried’s parameter r0. Since the atmospheric PSF is completely specified by this parameter we can obtain the kernel which is responsible for blurring of the observations. For the 7km path we also have simultaneous PSF calibrator from a source separated from the target by 0.1 mrad (70 cm from a distance of 7 km). Although some tilt anisoplanatism is already visible in the calibrator we perform deconvolution using this PSF.

We describe some of the encountered shortcomings of the methods: incapability of the most widely-used optimization criterion to capture perceptual image quality, limited capability of the myopic/blind codes to perform PSF update, and effect of the adaptive-optics image stabilization on the performance of multi-frame blind codes which rely, to some extent, on PSF diversity. We discuss future directions like maximum-a-posteriori deconvolution with statistical PSF prior and the development of new image quality metrics. We aim to produce a deconvolution algorithm which automatically extracts PSF from the observations (for non-compensated imaging), or from auxiliary wavefront-sensor data (for imaging with adaptive optics).

8355-34, Session 8

Modeling boost performance using a 2D implementation of the targeting task performance metric

B. L. Preece, D. P. Haefner, J. D. Fanning, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Using post-processing filters to enhance certain image characteristics, a process commonly referred to as boost, can significantly affect the performance of an EO/IR system. The Army’s target acquisition models currently use the Targeting Task Performance (TTP) metric to quantify sensor performance. The TTP metric accounts for each element in the system including: blur and noise introduced by the imager, any additional post-processing steps, and the effects of the Human Visual System (HVS). The current implementation of the TTP assumes separability, which can introduce significant errors when the TTP is applied to non-separable kernels. To accurately apply the TTP metric to systems incorporating boost, we implement a two-dimensional (2-D) version of the TTP metric. The accuracy of the 2-D TTP metric was verified through a series of perception experiments involving a number of additional post-processing techniques. The 2-D TTP metric has been incorporated into the Night Vision Integrated Performance Models (NV-IPM) allowing accurate system modeling of non-seperable image filters.

8355-35, Session 8

Performance evaluation of optimization methods for superresolution mosaicking on UAS surveillance videos

A. Camargo, The Univ. of North Dakota (United States)

Unmanned Aircraft Systems (UAS) have been widely applied into military reconnaissance and surveillance by exploiting the information collected from the digital imaging payload. However, the data analysis of UAS videos is frequently limited by motion blur; the frame-to-frame movement induced by aircraft roll, wind gusts, and less than ideal atmospheric conditions; and the noise inherent within the image sensors. Therefore, the super-resolution mosaicking on low-resolution UAS surveillance video frames, becomes an important task for UAS video processing and is a pre-step for further effective image understanding.

Here we develop a novel super-resolution framework which does not require the construction of sparse matrices. This method applied image operators in spatial domain and adopted an iterated back-projection method to conduct super-resolution mosaics from UAS surveillance video frames. The Steepest Descent method, Conjugate Gradient method and Levenberg Marquardt algorithm are used to numerically solve the nonlinear optimization problem in the modeling of super-resolution mosaic. A quantity comparison in computation time and visual performance of the super-resolution using the three numerical methods is performed. The Levenberg Marquardt algorithm provides a numerical solution to the least squares curve fitting, which avoids the time-consuming computation of the inverse of the pseudo Hessian matrix in regular singular value decomposition (SVD). The Levenberg Marquardt method, interpolating between the Gauss-Newton algorithm (GNA) and the method of gradient descent, is efficient, robust, and easy to implement. The results obtained in our simulations shows a great improvement of the resolution of the low resolution mosaic of up to 47.54 dB for synthetic images, and a considerable visual improvement in sharpness and visual details for real UAS surveillance frames. The convergence is generally reached in no more than ten iterations.

8355-36, Session 9

Understanding 3rd generation dual-band FLIR model versus measured range performance

R. Drake, Raytheon Network Centric Systems (United States)

The success of an EO/IR program hinges on a company's ability to design and produce a sensor system that meets or exceeds customer range performance requirements. Often these requirements are established in the advent of emerging threats. It is therefore essential that these systems meet the established requirements under the specified field conditions for our military to maintain an overmatch position and survivability of the soldier. Verification of the system range performance typically is limited to NVThermIP models, incorporating predicted and if available, measured performance characteristics of contributing components. However there have been significant advancements in sensor technology over the past few years with the continued development of small pitch 3rd Generation Dual Band (MWIR/LWIR) starring Focal Plane Array (FPA). In response, NVESD continues to evolve NVThermIP. It is because of these changes in both technology and modeling methodology that is it necessary to comprehend how the model is affected in relation to measured range performance.

The objective of this paper is to review methods for harmonizing NVThermIP 2009 modeled sensor range performance to measured range performance. Methods under review include improving 3rd Generation Dual Band staring FPA sensor modeling fidelity by fully characterizing the parameters that contribute to manual Detection, Recognition, and Identification (DRI) range performance, collection of range field data, and correlating both collected range field data and modeled performance to existing validated EO/IR systems.

8355-37, Session 9

Validating an analytical technique for calculating detection probability given time-dependent search parameters

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The search problem discussed in this paper is easily stated: given search parameters (P_∞,τ) that are known functions of time, calculate how the probability for a single observer acquiring a target grows with time. This problem was solved analytically in a previous paper. To investigate the validity of the solution, videos generated using NVIG software show the view from a vehicle traveling at two different speeds along a flat, straight road. Small, medium and large sized equilateral triangles, with the same gray level as the road but without texture, were placed at random positions on a textured road and military observers were tasked to find the targets. Analysis of this perception experiment yields experimental probability of detection as a function of time. Static perception tests enabled P_∞ and τ to be measured as a function of time for the small, medium and large triangles and this enabled comparison with an analytical calculation for probability of detection as a function of time.

8355-38, Session 9

A standard data set for performance analysis of advanced IR image processing techniques

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Modern IR cameras are increasingly equipped with built-in advanced (often non-linear) image and signal processing algorithms which can tremendously influence performance characteristics, like fusion, super-resolution, dynamic range compression etc. Traditional approaches to range performance modeling are of limited use for these types of equipment. Several groups have tried to overcome this problem by producing a variety of imagery to assess the impact of advanced signal and image processing. Mostly, this data was taken from classified targets and/ or using classified imager and is thus not suitable for comparison studies between different groups from government, industry and universities. To ameliorate this situation, NATO SET-140 has undertaken a systematic measurement campaign at the DGA technical proving ground in Angers, France, to produce an openly distributable data set suitable for the assessment of fusion, super-resolution, local contrast enhancement, dynamic range compression and image-based NUC algorithm performance. The imagery was recorded for different target / background settings, camera and/or object movements and temperature contrasts. MWIR, LWIR and Dual-band cameras were used for recording and were also thoroughly characterized in the lab. We present a selection of the data set together with examples of their use in the assessment of super-resolution and contrast enhancement algorithms. Also given are instructions on how to obtain access to the data sets.

8355-39, Session 9

Benchmarking image fusion algorithm performance

C. L. Howell, U. S. Army Night Vision & Electronic Sensors Directorate (United States)

Registering two images produced by two separate imaging sensors, having different detector sizes and fields of view requires one of the images to undergo transformation operations that may cause its overall quality to degrade with regards to visual task performance. This possible change in image quality could add to an already existing difference in measured task performance. Ideally, a fusion algorithm would take as input unaltered outputs from each respective sensor used in the process. Therefore, quantifying how well an image fusion algorithm performs should be base lined to whether the fusion algorithm retained the performance benefit achievable by each independent spectral band being fused. This study investigates an identification perception experiment using a simple and intuitive process for discriminating between image fusion algorithm performances. The results from a classification experiment using information theory based image metrics is presented and compared to perception test results. The results show an effective performance benchmark for image fusion algorithms can be established using human perception test data. Additionally, image metrics have been identified that either agree with or surpass the performance benchmark established.

8355-41, Session 10

Metrics for image-based modeling of target acquisition

J. D. Fanning, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

This paper presents a comparison of various image metrics used to create an image-based system performance model. The image-based system model uses an image metric to compare a given degraded image of a target, as seen through the modeled system, to the set of possible targets in the target set. This is repeated for all possible targets to generate a confusion matrix. The confusion matrix is used to determine the probability of identifying a target from the target set when using a particular system in a particular set of conditions. The image metric used in the image-based model should correspond closely to human performance. The performance of various metrics is compared using data with varying blur, noise, and sampling.

Image-based system performance modeling allows modeling of arbitrary image processing. Existing linear system models, such as the TTP metric model implemented in NVESD models such as NV-IPM, assume that the entire system is linear and shift invariant (LSI). The LSI assumption makes modeling nonlinear processes difficult, such as local area processing/contrast enhancement (LAP/LACE), turbulence reduction, and image fusion.

8355-42, Session 10

Assessing the performance of superresolution reconstruction algorithms

J. Dijk, K. Schutte, A. W. M. van Eekeren, P. Bijl, TNO (Netherlands)

For all military operations situational awareness is of great importance. This situational awareness and related tasks such as Target Acquisition can be acquired using cameras, of which the resolution is an important characteristic. Super resolution reconstruction algorithms can be used to improve the effective sensor resolution. In order to judge these algorithms and the conditions under which they operate best, performance evaluation methods are necessary. This evaluation, however, is not straightforward for several reasons.

First of all, frequency-based evaluation techniques alone will not provide a correct answer, due to the fact that they are unable to discriminate between structure-related and noise-related effects. Secondly, most super-resolution packages perform additional image enhancement techniques such as noise reduction and edge enhancement. As these algorithms improve the results they cannot be evaluated separately. Thirdly, a single high-resolution ground truth is rarely available. Therefore, evaluation of the differences in high resolution between the estimated high resolution image and its ground truth is not that straightforward. Fourth, different artifacts can occur due to super-resolution reconstruction, which are not known on forehand and hence are difficult to evaluate.

In this paper we present a set of new evaluation techniques to assess super-resolution reconstruction algorithms. Some of these evaluation techniques are derived from processing on dedicated (synthetic) imagery. Other evaluation techniques can be evaluated on both synthetic and natural images (real camera data). The result is a balanced set of evaluation algorithms that can be used to assess the performance of super-resolution reconstruction algorithms .

8355-43, Session 10

Weighted contrast metric for imaging system performance

B. P. Teaney, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

There have been significant improvements in the image quality metrics used in the NVESD model suite in recent years. The introduction of the Targeting Task Performance (TTP) metric to replace the Johnson criteria yielded significantly more accurate predictions for under-sampled imaging systems in particular. However, there are a number of cases which the TTP metric is ill suited to handle including high contrast and saturated images. In this paper a new metric for predicting performance of imaging systems is developed. This new 'clamped contrast' metric is characterized as a hybrid of the TTP metric and the Johnson criteria. Results from a number of historical perception studies are presented to compare the performance of the TTP metric and the Johnson criteria to the newly proposed metric.

8355-45, Session 10

Web-based psychophysics for determining the targeting task difficulty parameter

H. Nguyen, B. L. Preece, D. P. Haefner, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

Target acquisition performance assessment is continuously evolving with the addition of new sensor modalities, target types, and acquisition tasks. The task difficulty for each new target task must be calibrated using human perception experiments. Typically these perception experiments are performed in a carefully controlled environment taking into account viewing distance, magnification, screen resolution and luminance. In this paper we explore the possibility of obtaining the task difficulty parameter through the use of web-based perception experiments with un-controlled environmental settings. We show how increasing the number of observers through web-based perception testing mitigates the variation in observer viewing conditions. Successful implementation of web-based perception experiment should greatly improve the efficiency in adapting target acquisition models to new target types.

8355-61, Session 10

Improved fusing infrared and electro-optic signals for high-resolution night images

X. Huang, Stevens Institute of Technology (United States); R. Netravali, Columbia Univ. (United States); H. Man, V. B. Lawrence, Stevens Institute of Technology (United States)

Electro-optic (EO) images exhibit the properties of high resolution and low noise level, and it is a challenge to distinguish objects at night through infrared (IR) images, especially for objects with similar temperatures. Therefore, we have proposed a novel framework of IR image enhancement based on the information (e.g., edge) from EO images, which superimposes the detected edge of the EO image with the corresponding transformed IR image. Obviously, this framework will result in high resolution IR images and help distinguish objects at night. In this framework, we adopt the theoretical point spread function (PSF) proposed by Russell C. Hardie et al. for our IR image system, which is contributed by the modulation transfer function (MTF) of a uniform detector array and the incoherent optical transfer function (OTF) of diffraction-limited optics. In addition, we will design an inverse filter in terms of the proposed PSF to conduct the IR image transformation. In this paper, blending the detected edge of the EO image with the corresponding transformed IR image and the original IR image is the principal idea for the improved framework. This improved framework requires four main steps, which are: (1) inverse filter-based IR image transformation, (2) EO image edge detection, (3) registration and (4) blending the corresponding images. Simulation results will show the blended IR images and compare the improvement with superimposed results. Additionally, based on the same steps, simulation results will show the blended IR images on the assumption that only original IR images are available.

8355-46, Session 11

Locally adaptive contrast enhancement and dynamic range compression

R. Maschal, S. S. Young, U.S. Army Research Lab. (United States)

In surveillance applications, the visibility of details within an image is necessary to ensure detection. However, bright spots in images can occupy most of the dynamic range of the sensor, causing lower energy details to appear dark and difficult to see. In addition, shadows from structures such as buildings or bridges obscure features within the image, further limiting contrast. Dynamic range compression and contrast enhancement algorithms can be used to improve the visibility of these low energy details. In this paper, we propose a locally adaptive contrast enhancement algorithm based on the multi-scale wavelet transform to compress the dynamic range of images as well as increase the visibility of details obscured by shadows. Using an edge detector as the mother wavelet, this algorithm operates by increasing the gain of low energy gradient magnitudes provided by the wavelet transform, while simultaneously decreasing the gain of higher energy gradient magnitudes. Limits on the amount of gain imposed are set locally to prevent the over-enhancement of noise. The results of using the proposed method on aerial images show that this method outperforms common methods in its ability to enhance small details while simultaneously preventing ringing artifacts and noise over-enhancement.

8355-47, Session 11

Target-to-background contrast behavior of camouflage

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The purpose of military camouflage is to make an underlying object hard to spot or target, or to confuse a hostile observer as to its nature. A useful metric of this similarity between target and background is the contrast difference as measured at the visual display of an imaging sensor. The smaller the contrast difference, the harder it is to see the camouflaged object and the longer it takes to determine its nature. With all other parameters held equal, displayed contrast difference is a function of the spectral responsivity of the imaging sensor and the spectral radiometric properties of the camouflage and background. If reflected radiance is an important part of the imaged scene then the spectral nature of scene illumination is also an important component of that contrast difference. Military camouflages have been typically designed to work best in the visible band against one of the generic background types such as woodland, desert, arctic, etc., without significant attention paid to performance against a different background, type of scene illumination, or different waveband. This paper documents an investigation into the dependence of the contrast difference behavior of some unclassified personnel clothing and vehicle camouflages as a function of waveband, background, and scene illumination.

8355-48, Session 11

Performance modeling and assessment of infrared-sensors applicable for TALOS project UGV as a function of target/background and environmental conditions

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TALOS (Transportable and Autonomous Land bOrder Surveillance system - www.talos-border.eu) is an international research project co-funded from EU 7th Framework Program funds in Security priority. The main objective of TALOS project is to develop and field test the innovative concept of a mobile, autonomous system for protecting European land borders. Unmanned Ground Vehicles (UGVs) are major components of TALOS project. The UGVs will be equipped with long range radar for detection of moving vehicle and people, as well as long focal length EO/IR sensors allowing the operator to recognize and identify the detected objects of interest. Furthermore medium focal length IR sensors are used to allow the operator to drive the UGV. Those sensors must fulfill mission requirements for extremely various environmental conditions (backgrounds, topographic characteristics, climatic conditions, weather conditions) existing from Finland in the North and Bulgaria / Turkey in the South of Europe. An infrared sensor performance model was developed at ONERA in order to evaluate target detection, recognition and identification range for several simulations cases representative of the whole environmental variability domain. Results analysis allows assessing the operability domain of the infrared sensors. This paper presents the infrared sensor performance evaluation methodology and the synthesis of a large number of simulation results applied to two infrared sensors of interest: a medium / long range cooled MWIR sensor for observation and a short / medium range uncooled LWIR sensor for navigation.

8355-50, Session 11

Evaluating the efficiency of a nighttime, middle-range infrared sensor for applications in human detection and recognition

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In law enforcement and security applications, the acquisition of face images is critical in producing key trace evidence for the successful identification of potential threats. The stand-off distances most commonly used in face recognition (FR) systems are (a) short-range (<33 feet), suitable for applications such as identity verification at access

points, or (b) middle-range (<300 feet), suitable for applications such as building perimeter surveillance. Studies on short to middle-range face recognition systems that can operate in day time environments can be found in [1, 2, 3]. Efforts on mid-range FR at night are not mature yet (www.wvhtf.org)]. In this work we, first, use a near infrared (NIR) sensor designed with the capability to acquire images at middle-range stand-off distances at night. Then, we utilize our established face and eye detection algorithms, and, finally, determine the maximum stand-off distance where academic and commercial FR techniques can be utilized to efficiently recognize individuals at night. The distances that are investigated range from 30 to ~300ft. The study is focused on exploring and establishing the maximum capabilities of the NIR mid-range sensor to acquire good quality face images necessary for recognition.

[1] T. Bourlai et al., "Ascertaining Human Identity in Night Environments", Distributed Video Sensor Networks, Springer, 2011. [2] N. Kalka et al., "Cross-spectral FR in Heterogeneous Environments: A Case Study on Matching Visible to Short-wave Infrared Imagery", IJCB 2011. [3] Yao et al., "Improving long range and high magnification FR: Database acquisition, evaluation, and enhancement", CVIU 2007.

8355-51, Session 11

Compensating internal temperature effects in uncooled microbolometer-based infrared cameras

F. Pedreros, J. E. Pezoa, S. N. Torres, Univ. de Concepción (Chile) and Ctr. for Optics and Photonics, Univ. de Concepción (Chile)

It has been observed that the response of uncooled microbolometer-based infrared cameras fluctuates depending on the system thermal variations. That is, when the imager observes a constant radiation source, the temperature variations inside of the camera disturb the read-out digital counts yielding a fluctuating output. Noteworthy, these undesirable variations are part of the normal operation of a microbolometer, consequently, they must be compensated for to obtain a proper measurement. In an attempt to solve for this problem, manufacturers have introduced thermoelectric control systems to stabilize the internal temperature of the camera, while researchers have proposed variable biasing schemes to control the electrical response of each microbolometer in the array.

In this paper the effects of the internal temperature on the response of uncooled microbolometer cameras have been studied. To this end, different temperature profiles steering the internal temperature of the cameras have been generated, and a blackbody radiator source has been employed as a constant radiation input. The analysis conducted over the empirical data has shown the existence of statistical correlation between camera's internal temperature and the fluctuations in the read-out data. Thus, when measurements of the internal temperature are available, effective methods for compensating the fluctuations in the read-out data can be developed. This claim has been tested by developing a signal processing scheme, based on linear filters, to compensate the output of infrared cameras equipped with amorphous-Silicon and Vanadium-Oxide microbolometers.

8355-52, Poster Session

Determining detection, recognition, and identification ranges of thermal cameras on the basis of laboratory measurements and TTP model

J. Barela, M. Kastek, K. Firmanty, R. Dulski, P. Trzaskawka, Military Univ. of Technology (Poland)

TTP (Targeting Task Performance) model is widely used for the estimation of theoretical performance of observation devices. It is used, for example, in the NVTERM software and makes it possible to determine the detection, recognition and identification ranges for a standard target types o the basis of known technical parameters of analyzed device. Many theoretical analyses concerning TTP model can be found, as well as a few experimental, field test results. However the usability of the TTP model for the calculation of range parameters on the basis of laboratory test results has not been widely analyzed. The paper presents an attempt to apply TTP model for the estimation of range parameters of thermal cameras using laboratory measurement results of camera properties. The test stand consists of an infrared collimator, a standard infrared source, a set of test targets and a computer with data acquisition card. On this test stand the noise-related characteristics of an infrared cameras can be measured: (uniformity, SNR, 3-D noise, 1/f noise, NPSD, NETD) as well as those describing imaging capability (SiTF, MTF. Presampled MTF, CTF, MRTD). The method used for the measurement of aforementioned characteristics will be described and the algorithms used to finally estimate the range parameters of a tested thermal camera using TTP model.

8355-53, Poster Session

Testing of infrared image enhancing algorithm in different spectral bands

R. Dulski, P. Trzaskawka, T. Piatkowski, M. Kastek, Military Univ. of Technology (Poland)

The paper presents results of testing the infrared image quality enhancing algorithm based on histogram processing. Testing were performed on real images registered in NIR, MWIR, and LWIR spectral bands. Infrared images are a very specific type of information. The perception and interpretation of such image depends not only on radiative properties of observed objects and surrounding scenery. Probably still most important are skills and experience of an observer itself. In practice, the optimal settings of the camera as well as automatic temperature range or contrast control do not guarantee the displayed images are optimal from observer's point of view. The solution to this are algorithms of image quality enhancing based on digital image processing methods. Such algorithms can be implemented inside the camera or applied later, after image registration. They must improve the visibility of low-contrast objects. They should also provide effective dynamic contrast control not only across entire image but also selectively to specific areas in order to maintain optimal visualization of observed scenery. In the paper one histogram equalization algorithm was tested. Adaptive nature of the algorithm should assure significant improvement of the image quality and the same effectiveness of object detection. Another requirement and difficulty is that it should also be effective for any given thermal image and it should not cause a visible image degradation in unpredictable situations. The application of tested algorithm is a promising alternative to a very effective but complex algorithms due to its low complexity and real time operation.

8355-54, Poster Session

An experimental validation of the Gauss-Markov model for nonuniformity noise in infrared focal plane array sensors

O. A. Zapata, S. N. Torres, J. E. Pezoa, Univ. de Concepcion (Chile)

The aim of this research is to experimentally validate a Gauss-Markov model, previously developed by our group, for the nouniformity parameters of any infrared focal plane array detector. The Gauss-Markov processes assume the gain and the bias parameters of each detector as a random state variables modeled by the discrete-time process. The analysis developed in this work is a key issue considering that such model provides a mechanism for capturing the drift in the fixed-pattern-noise parameters.

Experimentation and infrared data collection have been conducted mainly by infrared cameras based in a microbolometer array (8-12um) and black body calibration sources within a temperature controlled

environment. In addition, a multipoint calibration method is applied in order to obtain the nouniformity parameters for an experimental system, which allows calculating the time series for the gain and the bias in steps of 0.5, 1, 1.5 and 2 hours.

Well known statistical procedure techniques to determinate if the Gauss-Markov model truly follow the fixed-pattern noise temporal drift are used to validate such model

8355-55, Poster Session

Modification of infrared signature of naval vessels

R. Dulski, Military Univ. of Technology (Poland); S. Milewski, Polish Naval Academy (Poland); M. Kastek, P. Trzaskawka, J. Barela, K. Firmanty, Military Univ. of Technology (Poland)

Every naval vessel can be detected and identified on the basis of its characteristics. The reduction of signature or matching it to the surrounding environment are one of the key tasks regarding survivability on a modern battlefield. The typical coatings applied on the outer surfaces of vessels are various kinds of paints. Their purpose is to protect the hull from aggressive sea environment and to provide camouflage in the visual spectrum as well as scatter and deflect microwave radiation. Apart from microwave and visual, infrared is most important spectral band used for detection purposes. In order to obtain effective protection in infrared the thermal signature of a vessel is required. It is determined on the basis of thermal contrast between a vessel itself and actual background and depends mostly on radiant properties of the hull. Such signature can be modified by altering apparent temperature values or the directions, in which the infrared radiation is emitted. The paper discusses selected methods of modification of vessel's infrared signature and effectiveness of infrared camouflage. Theoretical analyses were preceded by experimental measurements. The measurement-class infrared cameras and imaging spectroradiometers were used in order to determine the radiant exitance from different surface types. Experiments were conducted in selected conditions taking into account solar radiation and radiation reflected from elements of the surrounding scenery. Theoretical analysis took into account radiant angular properties of a vessel hull and attenuation of radiation after passing through the atmosphere. The study was performed in MWIR and LWIR ranges.

8355-56, Poster Session

Radiometric calibration software for MWIR cameras

H. Yang, J. Chun, Korea Advanced Institute of Science and Technology (Korea, Republic of); D. Seo, J. Yang, Korea Aerospace Research Institute (Korea, Republic of)

Korean Multi-purpose Satellite-3A (KOMPSAT-3A), which will weigh about 1,000 kg and will be located at a sun-synchronous orbit (SSO) of altitude 530 km, is scheduled to be launched in 2013. This is Korea's first satellite which will fly with a mid-wave infrared (MWIR) image sensor, which is currently being developed at Korea Aerospace Research Institute (KARI). The missions envisioned include forest fire surveillance, measurement of the sea surface temperature, national defense and crop harvest estimate. In this paper, we shall explain the software, test bed and calibration techniques for the infrared (IR) camera that we are currently developing.

We have developed MWIR scene generation software (based on MODTRAN) taking into account sky thermal emission, path emission, target emission, sky solar scattering and ground reflection. The generated scene is computed with the test-bed scenes of various cubic-shaped materials whose IR images are taken, with the records of the surface temperature, emissivity, and atmospheric data. This in-house scene generation software and the truth IR images are then used to evaluate the effectiveness of our calibration algorithms - the ground truth method, the in-scene (multi-band or multi-view angle) compensation techniques and the method that utilizes the atmospheric propagation model. Our simulation results so far indicate that the temperature and reflectance estimates using the ground truth method is quite accurate while the other two methods based on the in-scene method and the atmospheric propagation model based method have larger error.

8355-58, Poster Session

Automatic target detection from infrared imaging with the multivariate Gaussian mixture modeling

D. Lee, S. Yeom, Daegu Univ. (Korea, Republic of)

Infrared imaging is widely used for military and security applications since it can provide surveillance during day and night without security lighting. However, automatic target detection from infrared imaging is very challenging due to various noises and background clutters, which are caused by thermodynamic states and varying atmospheric conditions. This paper addresses target detection from infrared imaging with the multi-level expectation maximization method. The expectation-maximization algorithm solves the parameters of the Gaussian mixture model. The pixels in the image are segmented according to the posterior probability of the Gaussian mixture model. The normality of the different regions is tested to verify the validity of the proposed method. The multi-level expectation maximization is utilized to extract the target object region from the backgrounds and clutters. In the experiments and simulation, the proposed method is compared with other conventional approaches in term of the average probability error. It will be shown that the proposed method can achieve successful object detection with infrared imaging in the harsh environments.

8355-59, Poster Session

Evaluatıon of the effects of some remarkable internal and external factors on an infrared seeker

A. Uçar, B. Özkan, K. D. Kandemir, TÜBITAK SAGE (Turkey)

Seekers are one of the most important subsystems of guided aerial munitions such that they are used both to detect and to track prespecified target within specific engagement scenarios. Among them, infrared (IR) type ones constitute a significant portion of seekers. Actually, performance characteristics of seekers depend on some certain factors. Regarding the type of their sources, these factors can be classified as internal and external factors. Sensitivity, resolution, and dome materials happen to the the most significant internal factors acting on the IR seekers while atmospheric transmittance and visibility can be counted within the remarkable external factors. In this study, the basic effects of the above mentioned internal and external factors on the performance characteristics of a generic IR seeker is examined and corresponding interpretations are presented at the end of the work.

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8356-01, Session 1

Spectral shift of infrared LEDs and resistive sources

M. L. Fedde, Aerospace Testing Alliance (United States)

The Space Chambers at the Arnold Engineering Development Center (AEDC) are continually exploring new technologies to improve their characterization, calibration and mission simulation testing of imaging sensors capabilities. Part of this task is to develop and integrate methods to simulate high temperature sources (on the order of 3000K) while maintaining the integrity of the low radiometric background within the cryovacuum chambers. The High Temperature Source Simulator (HTSS) project at AEDC is exploring the use of laser diodes, LEDs and resistive sources of varying IR wavelengths to simulate these high temperature sources within AEDC's Space Chambers. A brief summary of previous work will be presented with a more detailed discussion of the recent cryospectral shift of the tested sources.

8356-02, Session 1

Contrast analysis for DMD-based IR scene projector

J. Rentz Dupuis, D. J. Mansur, S. Grant, S. P. Newbry, OPTRA, Inc. (United States)

OPTRA has developed a two-band midwave infrared (MWIR) scene projector based on digital micromirror device (DMD) technology; the projector is intended for training various IR tracking systems that exploit the relative intensities of two separate MWIR spectral bands. Next generation tracking systems have increasing dynamic range requirements (on the order of 12-bits) which current DMD-based projector test equipment is not capable of meeting. While sufficient grayscale digitization can be achieved with drive electronics, commensurate contrast is not currently available. It is towards this opportunity that OPTRA has initiated a dynamic range design improvement effort.

In this paper we present our work towards the measurement and analysis of contrast limiting factors including substrate scattering, diffraction, and flat state emissivity. We summarize the results of an analytical model which indicates the largest contributions to background energy in the off state. We present the methodology and results from a series of breadboard tests designed to characterize these contributions. Finally, we suggest solutions to counter these contributions.

8356-03, Session 1

Large-scale Si photonic infrared scene projector by light-down conversion

V. K. Malyutenko, V. Lashkaryov Institute of Semiconductor Physics (Ukraine)

Since the 1980s, the global technical efforts have largely been concentrated on wideband dynamic infrared scene projectors (DIRSPs) made of thermal emitters. Meantime, there are firm evidences that the technology and performance of thermal emitters have already plateaued and future advances in the field do not seem assured. And contrary, solid scientific background and recent experimental studies bring upon the evidence that due to new developments, photonic emitters are easy to meet many of new specific demands of which large format (cm scale), high frame rate (>200 Hz), ability to simulate cold scene (<270 K) without cooling an emitter itself are only a few to name.

The purpose of this work is to present the advantages of silicon pixel less photonic DIRSPs by light down conversion in a comparison with wideband thermal emitter devices available in the market or reported in experimental stages. There are several reasons for this. First, current IR sensor technologies are dramatically outpacing the ability to test them using state of the art IR scene projectors based on thermal emitters. Second, we wanted to show that photonic devices by light down conversion evolved from a scientific curiosity into technology poised to offer new capabilities to broadband DIRSPs application. Finally, we demonstrate that silicon becomes enabling material for emitting structures operating in near-, mid-, and long wave IR spectral bands.

8356-04, Session 1

Performance of bottom emitting isolated LWIR LED devices for IR scene projection

N. Das, U.S. Army Research Lab. (United States)

Infrared light emitting devices (LEDs) as light sources have recently been shown promising interest to be used in IR scene projection experiments. Large format (512 x 512) silicon nitride resistor arrays from Honeywell Corporation are presently used at the Advanced Simulation Center (ASC) of the Aviation and Missile Research, Engineering and Development Center (AMRDEC) of the US Army Aviation and Missile Command (AMCOM). However, long term reliability and the maximum temperature of emission are still the issues for IR resistor technology for HWIL applications [1]. IR LED arrays provide an extra benefit of fast switching and high emission temperature characteristics [2]. There exist various techniques to improve the out-coupling of IR light from GaSb substrate including grating [3], anti reflection coating [4] and slope mesa structure. However, we proposed here to enhance the light emission power from bottom emitting LWIR LED array by substrate thinning and isolating each pixel from others.

We used LWIR LED device with an interband cascade (IC) LED structure with 30 periods of InAs/GaInSb/AlSb type II active layers and n-type InAs/Al(In)Sb injection layers sandwiched between two p-type GaSb contact layers [4]. The total thickness of active and injection regions was 478 A ° and it was designed for a peak emission of 8 m at room temperature The IC LED structure was grown by a Varian Gen-II molecular beam epitaxial machine on a (100) n-type GaSb substrate. Following removal of the native oxide at 570° C, a 0.4 m p+ GaSb bottom contact layer was grown at a substrate temperature of 4900 C, as measured by a thermocouple located behind the wafer. The temperature was reduced to 4000 C for growth of the active/injection regions, which consisted of InAs, AlSb, GaSb, and InGaSb layers.

Light was collected and collimated by a 2-inch-aperture lens with a focal length of 2 inch. A one inch focal length lens was used to focus the light onto an HgCdTe detector. We used a pulsed current of 6 S pulse width and 30% duty cycle for light emission measurement. In Figure 1 (a), we present optical output power versus LED injection current (LI) for un-etched, lapped 300 m and etched devices. The total output power increases with injection current and attains saturation at higher current values. We observed about 20% increase of the optical power output by lapping the substrate for 300 m. However, we observed a three-fold increase in light intensity for the etched device compared to the un-etched device.

In figure 1 (b), we have shown the spectral response of the LWIR LED devices. The peak emission of the device occurs at 8 m. We will discuss in detail the pixel isolation process and apparent black body emission temperature from LWIR LED devices in full paper.

8356-05, Session 1

Motivation and challenges of polarization scene projectors

D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

Describe the potential use for polarization in sensors tested in HWIL facilities (who the customers are) and general description of polarization control and projection.

8356-06, Session 1

Testing updates for the infrared polarized scene generator demonstrator

P. S. Erbach, J. L. Pezzaniti, J. Reinhardt, T. Aycock, D. B. Chenault, B. Hyatt, Polaris Sensor Technologies, Inc. (United States)

Polarization signature information is becoming more useful as an added classifier in a variety of signature analysis applications. However, there are few infrared (IR) scene projection systems that provide the capability to inject target simulation images with polarization content into a seeker, or other imaging sensor. In a previous paper1 we discussed experimental results for an infrared (IR) polarized scene generator (PSG) concept demonstrator. The concept demonstrator operated in ambient environmental conditions and displayed polarized scenes of resolved targets. The IR PSG demonstrator that is the goal of this research must be capable of testing sensor systems operating in cryogenic-vacuum (cryovac or CV) environments. The IR PSG must also be able to accurately project scenes with unresolved polarized targets. As part of the development process, several potential PSG components are being tested in ambient and liquid nitrogen (LN2) environments to verify functionality and changes in behavior at ambient, vacuum, and cryovac conditions. This paper presents test data for several of the components. Components tested were an IR source, a polarizer, and motion control components. We also present test data for an imaging polarimeter being developed to validate the PSG.

8356-07, Session 1

JHU/APL's development of an agile IR scene projector based on carbon nanotubes

R. Fainchtein, D. M. Brown, K. M. Siegrist, A. H. Monica, The Johns Hopkins Univ. Applied Physics Lab. (United States); E. Hwang, S. D. Milner, C. C. Davis, Univ. of Maryland, College Park (United States)

The JHU/APL Guidance System Evaluation Laboratory facility has been testing the Standard Missile-3 since 2000 in a hardware-in-the-loop emulation environment using IR scene projectors (IRSPs). Current IRSPs contain arrays of miniature (50-μm-square) resistive heater elements controlled in real time to display a varying, complex IR scene to the seeker under test. Future units under test are bound to have larger IR focal plane array sensors and acquire images at faster frame rates. In order to accommodate the performance and oversampling demands to test future IR seekers, IRSPs will have to become larger and maintain refresh rates above the 200 Hz limit that the current technology employed in IRSPs can provide. A new approach is needed in order to be able to test future seekers in a hardware-in-the-loop configuration. We have been working on this problem and have proposed employing vertically aligned carbon nanotube (VACNT) arrays to produce faster and hotter scene rendering IRSPs. We have demonstrated feasibility of producing controlled VACNT arrays and using them to deliver blackbody-like IR scene rendering capabilities with rise and fall times 3 orders of magnitude faster that the currently used resistive elements IRSPs. In this talk we will present our results.

8356-08, Session 1

Photonic crystal multiband infrared scene projection technology

J. A. Wilson, Cyan Systems (United States); B. Burckel, Sandia National Labs. (United States); J. T. Caulfield, Cyan Systems (United States); S. M. Cogan, M. A. Massie, Nova Sensors (United States); R. J. Rapp, D. R. Snyder, Air Force Research Lab. (United States)

We report recent results from the Extremely High Temperature Photonic Crystal System Technology (XTEMPS) technology. The XTEMPS program has developed a Photonic Crystal (PhC) based high efficiency IR emitter array for use in the emerging generation of wide field of view high performance scene projectors. Cyan's approach provides high dynamic range, multispectral emission from SWIR to LWIR and is uniquely capable of accurately simulating very realistic system spectral signatures. The PhC array is fabricated from refractory materials to provide high radiance and long service lifetime. Cyan is teamed with Sandia National Laboratories, for design and fabrication of the emitter and with Nova sensors to utilize their advanced Read In Integrated Circuit (RIIC). PhC based emitters show improved in-band output power efficiency when compared to broad band "graybody" emitters due to the absence of out-of-band emission. Less electrical power is required to achieve high operating temperature and non-Lambertian emission pattern puts a large fraction of the emitted energy into a straight ahead beam. Both effects significantly boost effective radiance output. Cyan has demonstrated pixel designs compatible with Nova's medium format RIIC which ensures high apparent output temperatures with modest drive currents, and low operating voltages of less than five volts. Unit cell pixel structures for high radiative efficiency have been demonstrated and arrays using PhC optimized for up to four spectral bands have been successfully patterned and fabricated into high yield wafers.

8356-09, Session 1

Liquid crystal on silicon (LCOS) devices and their application to scene projection

T. K. Ewing, S. Serati, A. M. Linnenberger, H. Masterson, J. E. Stockley, J. R. Buck, Boulder Nonlinear Systems (United States)

Liquid Crystal on Silicon micro-displays are the enabling components on a variety of commercial consumer products including high-definition projection televisions, office projectors, camera view-finders, head-mounted displays and pico-projectors. The use and potential application of LCOS technology in calibrated scene projectors is just beginning to be explored. Calibrated LCOS displays and projectors have been built and demonstrated not only in the visible regime, but also in the SWIR, MWIR and LWIR. However, LCOS devices are not only capable of modulating the intensity of a broadband illumination source, but can also manipulate the polarization and/or phase of a laser source. This opens the possibility of both calibrated polarization displays and holographic projection displays.

8356-10, Session 1

The design, construction, and testing challenges of all reflective large format scene projector

D. A. Murray, S. H. Vogel, StingRay Optics, LLC (United States)

No abstract available

8356-11, Session 1

GaSb-based LEDs and LED addressable arrays for infrared scene projection

D. Westerfeld, Power Photonic (United Kingdom)

No abstract available

8356-12, Session 2

A hybrid non-uniformity correction method for IRSP arrays

J. D. LaVeigne, G. Franks, M. Prewarski, Santa Barbara Infrared, Inc. (United States)

Generating a high quality non-uniformity correction is an important part of producing a high fidelity infrared scene projection system (IRSP). A sparse grid method has been applied by several groups to produce accurate radiance for individual pixels. However, at low radiance levels sparse grid measurements can become difficult due to low signal to noise and long period system drift. We report results from a new method that combines sparse grid data collected a moderate and high radiance levels with a flood NUC method applied to low radiance data.

8356-13, Session 2

Update of IRSP development programs at SBIR

J. D. LaVeigne, K. Sparkman, S. W. McHugh, Santa Barbara Infrared, Inc. (United States)

We report the status of IRSP development programs ongoing at SBIR. Programs discussed will include the OASIS 1024 cryogenic array as well as status of the ultra-high temperature emitter program.

8356-14, Session 2

Radical rise-time enhancement of a resistive IRSP array

J. D. LaVeigne, G. Franks, Santa Barbara Infrared, Inc. (United States)

Pixels in the Mirage-XL series of emitter arrays have exhibited native rise-times of 5 to 8 msec, (10%-90%) depending on the beginning and ending radiance of a transition. Previous work has shown rise-time enhancement through the use of an overdrive algorithm that brought rise-times to <5 msec for all transitions when operated at the maximum full frame rate of 200Hz. The center 512x1024 portion of a Mirage-XL IRSP can also be operated in windowed mode at 400Hz. We report on the application of overdrive to a resistive array when operated a frame rates significantly faster than the native pixel response.

8356-15, Session 2

Design considerations for a high-temperature, high-dynamic range IRSP

J. D. LaVeigne, Santa Barbara Infrared, Inc. (United States); B. A. Sieglinger, MacAulay-Brown, Inc. (United States)

IRSP technology continues to advance producing scene projectors with higher apparent temperatures. While the maximum apparent temperature of an IRSP has increased, the minimum achievable apparent temperature has remained low and the requirements for good resolution at ambient apparent temperatures have not changed. The high radiance requirements along with the extended dynamic range and resolution requirements have consequences in overall IRSP system design. We discuss the implications of the high temperature, high dynamic range requirements on various IRSP systems.

8356-16, Session 2

Challenges associated with real-time nonuniformity correction (RNUC) of ultra-high-temperature scene projectors

B. A. Sieglinger, Air Force Research Lab. (United States)

No abstract available

8356-17, Session 2

Resistor arrays enabled by ‘quilt packaging’ edge interconnects

J. M. Kulick, Indiana Integrated Circuits, LLC (United States); J. D. Laveigne, Santa Barbara Infrared, Inc. (United States); J. M. Lannon, Jr., RTI International (United States); M. J. Padberg, Indiana Integrated Circuits, LLC (United States)

Resistive Arrays have become the technology of choice for most test and evaluation of infrared imaging systems. Fabrication yields of larger arrays make the economical production of arrays sizes larger than 1024x1024 extremely difficult. Attempts to “tile” small arrays into larger ones have met with limited success. Issues such as chip-to-chip I/O pitch, relatively large “seams” created by gaps between adjacent chips, and precision chip alignment all have posed significant problems to scaling up to large arrays. Integrating drive and control electronics further complicates this problem. The new microchip interconnect technology developed by Indiana Integrated Circuits, LLC and known as “Quilt Packaging” (QP) can alleviate many of the problems associated with tiling arrays, while delivering desired electronic and thermal performance. QP enables sub-micron chip-to-chip alignment, customizable chip I/O potentially as dense as 10 micron pitch, and can reduce “seams” between array elements to less than 10 microns. By integrating Quilt Packaging’s edge-interconnect structures with current Santa Barbara Infrared’s LFRA and RTI’s 3D packaging technologies, affordable, scalable, high-performance IR scene projectors can be fabricated.

8356-18, Session 2

256x256 high-performance thermal emitter array

K. Zhang, K Lab Corp. (United States)

No abstract available

8356-19, Session 3

Scene projection technology development for imaging sensor testing at AEDC

H. Lowry, Aerospace Testing Alliance (United States)

Arnold Engineering Development Center (AEDC) is tasked with vis-to-LWIR imaging sensor calibration and characterization, as well as Hardware in the Loop (HWIL) testing with high-fidelity complex scene projection to validate sensor mission performance. They are thus involved in the development of technologies and methodologies that

are used in space simulation chambers for such testing. These activities support a variety of program needs such as space situational awareness (SSA). This paper provides an overview of pertinent technologies being investigated and implemented at AEDC.

8356-20, Session 3

Application of scene projection technologies at the AMRDEC SSDD HWIL Test Facilities

D. A. Saylor, Optical Sciences Corp. (United States); J. A. Buford, Jr., U.S. Army Aviation & Missile Research, Development and Engineering Ctr. (United States); G. H. Ballard, U.S. Army Aviation & Missile Research, Development and Engineering Ctr (United States)

No abstract available

8356-21, Session 3

Infrared projector optical system characterisation and its application to nonuniformity correction

L. Swierkowski, R. A. Joyce, C. L. Christie, Defence Science and Technology Organisation (Australia)

Continued technological advances in infrared imaging and the proliferation of high quality infrared sensors has created an increasing need for improvements in the fidelity of infrared scene projection for HWIL testing and evaluation. In the case of resistor array projectors, performing a high quality nonuniformity correction (NUC) is essential for achieving high projected scene fidelity. This is especially important for low contrast applications where the temperature resolution demands can be high. From the practical point of view it is also highly desirable that the speed of the NUC process be improved without its quality being jeopardised. Another practical challenge is the ability to perform NUC using less expensive cameras where both low resolution and temporal effects may significantly influence the correction process.

In this paper we report on our continuing efforts to develop a fully autonomous high fidelity NUC process. In particular, we describe our implementation of an enhanced procedure for characterisation of the projector-camera optical system. It addresses the issue of sampling artefacts, either due to projector system optical distortion or to the use of a low resolution NUC camera. The information obtained from this procedure is used in our new NUC routine for the rapid derivation of precise NUC coefficients in the minimal number of iterations. Our procedure is fast and therefore one of its benefits is the alleviation of camera temporal effects such as drift. For some cameras, drift represents one of the primary limitations for performing accurate NUC. In order to isolate the correction process from temporal effects, we have implemented a new multi-point multi-temperature camera calibration procedure that allows the corrections to be applied in real time. We describe our current procedures and discuss other possible NUC improvement strategies.

8356-22, Session 3

Performance parameters in the design of flight motion simulators

R. W. Mitchell, Ideal Aerosmith, Inc. (United States)

A Flight Motion Simulator (FMS) requires a configuration to satisfy test performance specifications. The design must account for the FMS to carry the payload and meet the accuracy and dynamic requirements. The facility power must be sufficient to provide maximum accelerations and rates either continuously or with a specified duty cycle. High dynamics also require a substantial pier design to maintain pointing accuracies throughout the system-operating envelope.

Parameter curves are presented of the major specifications affecting system cost in relation to performance. With the major discriminators determined, relationships are provided for the other parameters as electro-magnetic interference (EMI), facility vibration, and noise.

A typical set of specifications is presented that can be used as a baseline and a beginning point for FMS performance requirements.

8356-23, Session 3

Common hardware-in-the-loop framework development

H. J. Kim, U.S. Army Aviation & Missile Research, Development and Engineering Ctr. (United States)

An approach to streamline the Hardware-In-the-Loop (HWIL) simulation development process is under testing. This Common HWIL technique will attempt to provide a more flexible, scalable system. The overall goal of the Common HWIL system will be to reduce cost by minimizing redundant development, operational labor and equipment expense. Initial design is complete and test articles are under development. This paper will present current results from testing several prototype boards and future plans of the development. Also, the paper will present the results from utilizing Xilinx's RocketIO multi-gigabit transceivers as communications architecture in a Common HWIL environment.

The U.S. Army Research, Development and Engineering Command (RDECOM) Aviation and Missile Research, Development and Engineering Center (AMRDEC) has been pursuing the establishment of a Common HWIL interface as well as a rapid prototype laboratory based on the resulting standard. The system is planned to utilize a standardized overall architecture as well as consistent component design to allow faster development and integration during facility buildup. It is also being developed to utilize reusable modules designed for adaptation to specific test articles.

The overarching architecture will be scalable to accommodate stand-alone, bench top experiments of a single test article, or a composition of multiple, geographically dispersed test articles spanning numerous weapon systems. Test articles may be hardware only, processor-in-the-loop, or all-digital representations. This will permit Common HWIL to integrate hardware items from various technologies in any combination desired. Multiple Common HWIL laboratories may also be linked via suitable protocol as another technique for achieving force-on-force level simulations. With the standard interfaces and an external synchronization concept, the common HWIL approach will provide a capability that assures validity and repeatability of real-time simulation results.

8356-24, Session 3

Dynamic plume simulator

Y. G. Soskind, R. Gifford, DHPC Technologies (United States)

Hardware-in-the-loop (HWIL) simulation technology has emerged as an effective means of reducing the risks associated with development of real-time systems that need to react to dynamically changing parameters, as well as reducing the operational costs of performing the live tests.

Presented Dynamic Plume Simulator (DPS) constitutes a complex electro-optical system that is capable of dynamic real-time simulation of aircraft and missile plumes in laboratory environments. DPS system produces real-time simulation of the different plume phases during the fly out scenarios, including proximity and atmospheric effects. The system is capable of real-time adjustment of the size and radiance of the emitting aperture while maintaining high spatial uniformity over a significant field of regard. DPS radiation spectra is tailored to match the spectral composition of a given plume type under consideration.

In this paper, we discuss development of DPS system based on the integration of several real-time controlled electro-optical modules that produces high fidelity plume characteristics for HWIL simulations. DPS design is based on a modular approach, providing flexibility to customize and expand the system to address the emerging requirement and future needs. We present results of DPS design and characterization as a part of HWIL laboratory. The characterization results demonstrate a highly reliable and consistent operation of the system producing high fidelity plume signatures.

We show that optical design optimization for packaging and integration, as well as software-assisted calibrations significantly reduce alignment complexity and DPS integration costs.

Conference 8357: Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XVII

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8357-01, Session 1

Pedemis: a portable electromagnetic induction sensor with integrated positioning

B. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); F. Shubitidze, Thayer School of Engineering at Dartmouth (United States); J. P. Fernandez, Univ. of Massachusetts Amherst (United States); T. M. Grzegorczyk, Delpsi, LLC (United States); K. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States)

Recently, several next generation EMI instruments have shown promise in improving data quality and thereby increasing the accuracy and dependability of detection and discrimination postprocessing algorithms. To date, most of these instruments have been cart based systems meant for larger surveys with the exception of the MPV and the GEM-3D+ instruments. While significant improvements have been made, disadvantages remain such as uncertainties in positioning systems, non-portability in rugged/treed terrain, the physical coupling of the transmitter and receiver coil, and limits on easy operator choice of the spatial resolution of data for discrimination purposes.

We are developing a 2-person portable time domain EMI instrument that has a detachable receiver assembly called Pedemis (PortablE Decoupled EMI System). The primary coils are placed on the ground at the beginning of an interrogation, while the receiver coils are either moved around above the primary coils or are placed at strategic locations for higher SNR static shots. We report here on our work in estimating the expected positioning accuracy of the proposed instrument. We also show the final design of Pedemis including hardware and operational protocols. Initial data from the instrument over canonical targets under lab conditions will also be shown.

8357-02, Session 1

Optimizing EMI transmitter and receiver configurations to enhance detection and identification of small and deep metallic targets

J. P. Fernandez, A. Bijamov, Thayer School of Engineering at Dartmouth (United States); I. Shamatava, Sky Research, Inc. (United States); B. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); K. O'Neill, F. Shubitidze, Thayer School of Engineering at Dartmouth (United States)

Current electromagnetic induction (EMI) sensors of the kind used to discriminate buried unexploded orndance (UXO) can detect targets down to a depth limited by the geometric size of the transmitter (Tx) coils, the amplitudes of the transmitting currents, and the noise floor of the receivers (Rx). The last two factors are not independent: for example, one cannot detect a deeply buried target simply by increasing the amplitude of the Tx current, since this also increases the noise and thus does not improve the SNR. The problem could in principle be overcome by increasing the size of the Tx coils and thus their moment. Current multi-transmitter instruments such as the TEMTADS sensor array can be electronically tweaked to provide a big Tx moment: they can be modified to transmit signals from two, three or more Tx coils simultaneously. We investigate the possibility of enhancing the deep-target detection capability of TEMTADS by exploring different combinations of Tx coils. We model different multi-Tx combinations within TEMTADS using a full-3D EMI solver based on the method of auxiliary sources (MAS). We determine the feasibility of honing these combinations for enhanced detection and discrimination of deep targets. We investigate how to improve the spatial resolution and focusing properties of the primary magnetic field by electronically adjusting the currents of the transmitters. We apply our findings to data taken at different UXO live sites.

8357-03, Session 1

Live-site, production-level, metal-mapper data sets inversion and classification studies

F. Shubitidze, Thayer School of Engineering at Dartmouth (United States) and Sky Research, Inc. (United States); J. Miller, J. Keranen, Sky Research, Inc. (United States); A. Bijamov, Thayer School of Engineering at Dartmouth (United States)

Advanced EMI models, based on the OrthoNormalized Volume Magnetic Source (ONVMS) and incorporating joint diagonalization pre- and post-processing and differential evolution optimization, alongside a Gaussian mixture clustering/classication algorithm, are applied to invert for the locations and orientations of the targets of interest in the course of some live-site MetalMapper (MM) production-level data sets at different military facilities. The model provides at least three time-dependent intrinsic parameters for each potential target; the magnitude and time evolution of the total ONVMS parameters depend on the size, geometry, and material composition of the corresponding object. These parameters form feature vectors that can be used to discriminate between UXO and clutter. The studies were carried out using two sets of production-level MM data cued data sets collected independently by teams from Parsons and CH2M HILL. The MM sensor directly provides a measured multi-static response (MSR) data matrix whose egenvalues reveal the number of targets contributing to the signal and their initial classification features. Knowledge of the target number streamlines an ONVMS-DE-based inversion that yields intrinsic signatures for each potential target. These intrinsic parameters are then clustered, the anomalies are classified using the Gaussian mixture approach, and finally a production-team-specific dig-list is generated and submitted to the administrators for scoring. The scored classification results are illustrated.

8357-04, Session 1

Inversion-free discrimination of unexploded ordnance in real time

F. Shubitidze, J. P. Fernandez, Thayer School of Engineering at Dartmouth (United States); I. Shamatava, Sky Research, Inc. (United States); A. Luperon, Thayer School of Engineering at Dartmouth (United States); B. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); K. O'Neill, Thayer School of Engineering at Dartmouth (United States)

Advanced EMI sensors currently feature multi-axis illumination of targets and tri-axial vector sensing, or exploit multi-static array data acquisition. These sensors directly provide multi-static response (MSR) data matrices. To take advantage of the rich data sets that these sensors provide, we recently introduced a novel data pre-and post-processing technique based on joint diagonalization (JD). Most current UXO detection and discrimination techniques attempt to simultaneously extract intrinsic and extrinsic parameters from measured secondary EMI signals using linear/nonlinear inversion, a computationally costly process. Not knowing the number of targets complicates the task further. Our recent live-site UXO classification studies showed that JD can be used to obtain a quick estimate of the number of potential targets in each case and even, in many instances, to classify those targets at the

data-pre-processing stage, in real time and without invoking a forward model. JD estimates the eigenvalues and eigenvectors of the MSR data matrix. The number of nonzero eigenvalues relates to the number of illuminated targets. Moreover, the time-decay patterns of these non-vanishing eigenvalues are intrinsic properties of the targets to which they correspond. We outline a JD-based classification algorithm for TEMTADS and MM sensors, and then demonstrate discrimination results which use the time-decay curves of eigenvalues as discrimination features in a Gaussian mixture model classification technique. Examples are shown from Camp Butner and Camp Beale demonstrations.

8357-05, Session 1

Camp Beale live-site, hand-held EMI sensors data inversion and classification using advanced EMO models

I. Shamatava, Sky Research, Inc. (United States); F. Shubitidze, J. P. Fernandez, A. Bijamov, Thayer School of Engineering at Dartmouth (United States); B. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); K. O'Neill, Thayer School of Engineering at Dartmouth (United States)

In this paper advanced EMI models and classification algorithms are applied to live site hand held EMI (2x2 3D TEMTADS and MPV-II) sensors data sets. The models, that combines a forward model based on volumetric discrete orthonormalized mutually coupled magnetic dipoles, joint diagonalization (JD) preprocessing, differential evolution (DE) optimization, and classification using Gaussian mixture models, is suitable for the discrimination of single or multiple targets. In this study, first the Joint Diagonalization technique is used to estimate background noise levels and target numbers for each cell, then the combined ONVMS-DE algorithm is employed and targets discrimination features, such as total ONVMS, are extracted from EMI data. Next, the extracted total ONVMS are used in well-developed and tested unsupervised classification approaches to discriminate hazardous targets of interest reliably and effectively from non-hazardous items such as cultural debris, range-scrap, and shrapnel. The classification results are presented for Camp Beale, CA live-site, that is partially wooded and contaminated with a mix of munitions 37 mm, 60 mm, 81 mm and 105 mm types. Two advanced portable 2x2 3D-TEMTADS and MPV-II EMI sensor data, collected over nine hundred eleven anomalies, are processed independently and targets intrinsic (total volume magnetic source (NVMS) i.e. the size, shape and material properties) and extrinsic (location, depth, orientation) parameters are estimated. The intrinsic parameters are used for classification and sensor specific -independent dig-lists are generated for each EMI instrument. The dig-lists are submitted to the Institute of Defense Analysis (IDA) for independent scoring. The advanced models classification performances for each portable EMI sensors are assessed and illustrated based on the independent scored results.

8357-06, Session 2

Large loop EMI sensor for detection of deeply buried munitions in magnetic soils

J. Miller, J. Keranen, G. Schultz, Sky Research, Inc. (United States); S. Billings, Sky Research, Inc. (Australia)

Land reclamation efforts in post-conflict regions are often hampered by the presence of Unexploded Ordnance (UXO) or other Explosive Remnants of War (ERW). Surface geophysical methods, such as Electromagnetic Induction (EMI), are typically applied to screen rehabilitation areas for UXO prior to excavation; however, detection of large, deeply buried munitions is often problematic for conventional EMI sensors due to inherent sensor range limitations. While magnetometer-based systems extend detection range beyond that afforded by conventional EMI sensors, highly magnetic soil environments can significantly degrade the performance of passive magnetic field sensors. This paper presents a novel active source EMI sensor that offers extended detection ranges (> 2m) with minimal sensitivity to magnetic geology. The Ultra Deep Search (ULTRA) EMI system employs a large (20 - 40m), stationary, surface-laid transmitter loop that produces a relatively uniform magnetic field within the search region. This primary field decays slowly with depth due to the non-dipolar nature of the field within the search volume. An array of 3-axis receiver cubes measures the time derivative of secondary field decays produced by subsurface metallic objects. The large-loop transmitter combined with the vector sensing induction coil receivers produces a deep search capability that remains robust in environments containing highly magnetic soils. In this paper, we assess the general detection capabilities of the ULTRA system and present data collected over a set of standardized UXO targets. Additionally, we evaluate the potential for target classification based on analysis of data and target model features.

8357-07, Session 2

Feature extraction and processing of spatial frequency-domain electromagnetic induction sensor data for improved landmine discrimination

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Frequency-domain electromagnetic induction (EMI) sensors have been shown to provide target signatures which enable discrimination of landmines from harmless clutter. In particular, frequency-domain EMI sensors are well-suited for target characterization by inverting a physics-based signal model. In many model-based signal processing paradigms, the target signatures can be decomposed into a weighted sum of parameterized basis functions, where the basis functions are intrinsic to the target under consideration and the associated weights are a function of the target sensor orientation. When spatial data is available, the diversity of the measured signals may provide more information for estimating the basis function parameters. After model inversion, the basis function parameters can be used as features for classifying the target as landmine or clutter. In this work, feature extraction from spatial frequency-domain EMI sensor data is investigated. Results for data measured with a prototype frequency-domain EMI sensor at a standardized test site are presented. Preliminary results indicate that structured relevance vector machine (RVM) regression model inversion using spatial data provides stable, and sparse, sets of target features.

8357-08, Session 2

On the estimation of target depth using the single-transmit multiple-receive metal detector array

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This paper investigates the use of the Single Transmit Multiple Receive (STMR) metal detector (MD) array to estimate the depth of metal targets, such as 155mm shells. This problem has been investigated by a number of researchers before and the processing was along the down-track. The proposed method takes a different approach by exploring the MD responses in cross-track to do the depth estimation. It is found that the energy spread of the MD output is narrower for shallow targets and wider for deeper targets. Based on this observation, a method is derived to estimate the depth of a target. Experimental results from the data collected at an U.S. Army test site will be presented.

8357-09, Session 2

Robust estimation of the discrete spectrum of relaxations from multiple-electromagnetic induction responses

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The EMI response of a target can be accurately modeled by a sum of real exponentials. However, it is difficult to obtain the model parameters from measurements when the number of exponentials is unknown and the summands are highly correlated. We previously proposed two robust methods for estimating the model parameters from a single EMI measurement. These methods have been applied to laboratory as well as field data.

In the laboratory or the field, multiple measurements are often available for a target of interest. Because different measurements from the same target share the same relaxation time constant, one can exploit this property to increase the estimation accuracy when multiple measurements are available.

In this paper, we propose an algorithm that estimates the EMI model parameters by using multiple measurements simultaneously. This is done by recasting the EMI estimation problem into the problem of recovering a single underlying sparse model that represents a entire set of multiple-measurement vectors (MMV). To cast the EMI estimation problem into a MMV problem, the EMI problem is reformulated into a linear system by enumerating the relaxation parameter space. The model parameters are then estimated through iterative reweighted algorithms. The proposed method is tested against synthetic, laboratory, and field data, and is demonstrated to deliver accurate and stable estimates.

A crucial step in the algorithm design is properly selecting the regularization parameter to handle noise in the measurements. We propose a simple quadratic regularization-parameter selection rule can provide satisfactory results under noise.

8357-83, Session 2

Landmine detection using two-tapped joint orthogonal matching pursuits

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Joint Orthogonal Matching Pursuits (JOMP) is used here in the context of landmine detection using data obtained from an electromagnetic induction (EMI) sensor. The response from an object containing metal can be decomposed into a discrete spectrum of relaxation frequencies (DSRF) from which we construct a dictionary. A greedy iterative algorithm is proposed for computing successive residuals of a signal by subtracting away the highest matching dictionary element at each step. The final confidence of a particular signal is a combination of the reciprocal of this residual and other factors including the mean of the complex component and magnitude of the real component. A two-tap approach comparing signals on opposite sides of the geometric location of the sensor is examined and found to produce better classification. It is found that using only a single pursuit does a comparable job, greatly reducing complexity and allowing for real-time implementation in automated target recognition systems. We also discuss various types of subsurface objects detectable using the JOMP approach and show that detection is correlated with coherent Argand diagrams.

8357-10, Session 3

Progress on a system for measuring wide-band electromagnetic induction responses

W. R. Scott, Jr., M. J. McFadden, Georgia Institute of Technology (United States)

Wide-band electromagnetic induction (EMI) systems have been shown to identify land mines with fewer false alarms than simple metal detector systems. This reduction in false alarms is achieved through signal processing algorithms that utilize the additional information contained in the frequency response to determine whether a flagged area is dangerous. Modern algorithms often make this identification through machine-learning approaches that require a large amount of field data to build the classifiers. Obtaining this data can be time-consuming, costly and often slows algorithm development. An important first step toward speeding up this process would be to develop physically accurate wide-band models for common objects that would allow algorithms to be tested quickly against reliable synthetic data.

In this work, we present recent progress on a system for measuring and characterizing wide-band EMI responses of common objects found in field data. The layout of the system is presented and the major development issues are discussed. Measurements for several metallic and magnetic objects are shown. When theoretical predictions are available, the measured responses show good agreement. Metallic target responses are characterized as a sum of current loops, each with a characteristic relaxation frequency. This model is physically justifiable and represents a large amount of data about an object's magnetic response in a very compact form. A discussion of the inversion technique for mapping magnetic responses to the wide-band scattering model is also included.

8357-11, Session 3

Location and orientation estimation of buried targets using electromagnetic-induction sensors

K. R. Krueger, W. R. Scott, Jr., J. H. McClellan, Georgia Institute of Technology (United States)

Dictionary matching techniques have been an effective way to detect the location and orientation of buried targets. Useful buried target detection dictionaries can be created using ground penetrating radar (GPR) and EMI responses. The problem arises when trying to create a comprehensive dictionary that can accurately find location and orientation information for all types of useful targets. It is difficult to obtain orientation using GPR, and simple frequency domain matching techniques with EMI require a dictionary to contain the response for every possible target or clutter that could be encountered. For example, if a dictionary was created to find the location and orientation of a target in three spatial dimensions, the dictionary would need 7-dimensions: three spatial, one target type, one frequency, and two orientations.

This paper shows that with using the discrete spectrum of relaxation frequencies (DSRF), and the singular value decomposition (SVD), the size of a dictionary used to obtain location and orientation estimates of buried targets can be greatly reduced. Taking the DSRF response allows the target and frequency dimensions to be completely eliminated by assuming every target can be represented by a small number of dipoles. The SVD is used to further reduce the dictionary size by another one to two orders of magnitude because the downrange response of the target can be represented by a very small number of singular vectors. Using these dimensionality reducing techniques, a dictionary can be created of a feasible size to obtain location and orientation estimates of buried targets.

8357-12, Session 3

Induction detection of concealed bulk banknotes

C. Fuller, A. Chen, Univ. of Washington (United States)

Bulk cash smuggling is a serious issue that has grown in volume in recent years. By building on the magnetic characteristics of paper currency, induction sensing is found to be capable of quickly detecting large masses of banknotes. The results show that this method is effective in detecting bulk cash through concealing materials such as plastics, cardboards, fabrics, and aluminum foil. The significant difference in the observed phase between the received signal caused by conducting materials and ferrite compounds, found in banknotes, provides a good indication that this process can overcome the interference by metal objects in a real sensing application. This identification strategy has the potential to not only detect the presence of banknotes, but also the number, while still eliminating false positives caused by metal objects.

8357-13, Session 3

Pinpointing error analysis of metal detectors under field conditions

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The detection performance of metal detectors has been commonly evaluated in field trials by counting number of hits and misses. Metal detectors are also used to locate targets and the location performance has been evaluated previously only in laboratory. The performance probably differs that in the field. In this paper, the evaluation of the location performance based on the analysis of pinpointing error is discussed. The data for evaluation were collected in a blind test in the field. The test was originally carried out for the evaluation of detection performance with the hit/miss analysis. The analysed pinpointing performance can be seen as the performance under field conditions. The pinpointing accuracy obtained in this way can be used to establish standard operating procedures of clearance operations. Further, the performance is discussed in relation to the search head and footprint dimensions. The result shows that a smaller footprint demonstrates a higher pinpointing accuracy, although a larger footprint is advantageous to detect targets.

8357-14, Session 4

Towards a military-standard wireless sensor platform for the detection of improvised explosive devices

A. Gunasekaran, N. Patel, S. Sedigh, Missouri Univ. of Science and Technology (United States)

This paper describes the development and testing of a wireless sensor network for the detection of improvised explosive devices (IEDs). The primary design objectives were compliance with military standards for hardware, software, and communication; accuracy, autonomy, and robustness to harsh operating conditions. The proposed platform includes a base station and sensor nodes, all of which are wireless, designed for low power consumption, and capable of short- and long-range communication of data and alerts. Considerable computational capability and efficient design enable the interfacing of numerous analog and digital sensors to the platform, facilitating reliable multimodal sensing and detection.

The efforts described are part of a broader IED detection initiative, where multiple sensing devices developed by independent groups are linked to increase the reliability of detection. The base station described in this paper is responsible for aggregation of the data from all sensor devices and communication of this data and any alerts generated to designated entities in the outside world. As such, interoperability was a key design objective for the base station. We describe the methods by which this interoperability is achieved, as well as efforts associated with integration of third-party sensor nodes with the proposed platform. The proposed solution can be extended to other applications that require sensing, detection, and reporting; structural health monitoring is one example.

8357-15, Session 4

Experimental investigation of buried landmine detection using time division multiplexing of multibeam laser Doppler vibrometer channels

R. D. Burgett, V. Aranchuk, J. M. Sabatier, I. Aranchuk, The Univ. of Mississippi (United States)

Producing vibration images of buried landmines using a multi-beam laser Doppler vibrometer (MB-LDV) operating from a stationary platform have been accomplished in the past. Detection from a continuously moving platform can reduce the time of detection compared to stop-and-stare measurement. However, there is a speed limitation, imposed by the required spatial and frequency resolution. NCPA proposed a concept of time division multiplexing of laser beams of a MB-LDV to overcome that speed limitation. The system, based on 16-beam MB-LDV, has been built and experimentally tested at an Army test facility. Vibration velocity profiles of buried mines have been obtained at different system speeds. Algorithms for speckle noise reduction in continuously moving MB-LDV signals have been developed and explored. The results of the current data collection, recent past data collection as well as the results of the effectiveness of speckle noise reduction techniques are presented.

8357-16, Session 4

Synthetic aperture acoustic imaging of non-metallic cords

J. Vignola, J. A. Judge, The Catholic Univ. of America (United States); S. S. Bishop, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. E. Good, The Catholic Univ. of America (United States); P. M. Gugino, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Soumekh, Soumekh Consultant (United States)

The remote detection of non-metallic cords in an outdoor environment using synthetic aperture acoustic (SAA) is investigated experimentally. Interest in this detection approach stems form the fact that non-metallic cords are not readily detectable with synthetic aperture radar (SAR) and that this imaging approach represents a relatively inexpensive alternative or supplement to SAR. The measurement system is comprised of a mobile acoustic transceiver (a speaker and microphone) that broadcasts a burst chirp with a bandwidth of 2-15 kHz. The recorded signal is used to form a two-dimensional image of the distribution of acoustic scatterers within the scene. For this study, five different diameters (2-15mm) of nylon cord laid on the ground were imaged in various configurations. These measurements were made in the presence of urban ambient noise of varying levels. The goal of this study was to identify the effect of environmental noise and other parameters on detectability. Experimental results show that non-metallic cords can be detected acoustically, and that increasing resolution by increasing acoustic frequency comes at the expense of scattering strength.

8357-17, Session 5

Overview of computational testbed for evaluating EO/IR sensor systems

R. V. Kala, J. R. Fairley, S. J. Price, A. R. Carrillo, S. E. Howington, O. J. Eslinger, A. M. Hines, R. A. Goodson, E. S. Berney IV, J. R. Ballard, Jr., U.S. Army Engineer Research and Development Ctr. (United States)

The U.S. Army Engineer Research and Development Center (ERDC) had developed a near-surface computational testbed (CTB) for modeling geo-environments. This modeling capability is used to predict and improve the performance of current and future-force sensor systems for surface

and near-surface threat detection for a wide range of geo-environments. The CTB is a suite of integrated models and tools used to approximately replicate geo-physical processes of radiometric, meteorological, moisture transport, and thermal transport that influence the resultant signatures of both natural and man-made materials, as perceived by the sensors.

The CTB is designed within a High Performance Computing (HPC) framework to accommodate the size and complexity of the virtual environments required by the CTB. This HPC capability allows the CTB to replicate geophysical processes and subsurface heterogeneity with high levels of realism, and provide new insight for identifying the geophysical processes and environmental factors that significantly affect the signatures sensed by multispectral imaging, near-infrared, mid-wave infrared, long-wave infrared, and ground penetrating radar sensors. This effort also is helping to quantify the performance and optimal time-of-use for sensors to detect threats in highly heterogeneous geo-environments, by reducing false alarms from automated target recognition algorithms.

8357-18, Session 5

Examining the influence of sub-surface characterization on simulated IR imagery

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It is well known that the micro-topographic features of a particular location can influence field-collected IR imagery. As a result, they can also affect the performance of automated target recognition algorithms and decisions based on their results. Other significant contributors to false alarms and issues with probabilities-of-detection include the relative locations of vegetation and local changes in soil types or properties. For example, a change in the retention of soil moisture alone is known to contribute to false alarms due to changes in radiative and thermal properties of wet versus dry soil. In this work, the distribution of material zones will be examined as they relate to simulated IR imagery.

The U.S. Army Engineer Research and Development Center (ERDC) has developed a software suite that replicate the significant geo-physical processes which affect the thermal signatures sensed by infrared imaging systems. This suite of models also includes an electro-optical/infrared (EO/IR) sensor model that produces synthetic thermal imagery. The EO/IR sensor model can be adapted to replicate the performance of other infrared sensor systems. Many aspects of field data collection efforts (weather, etc.) cannot be controlled nor changed later. Within a computational framework, plant and object locations, as well as weather patterns can all be changed. This is also true for material zones. Both the zonation and the material properties themselves can be adjusted and given any type of distribution that is desired. In particular, the differences between the two approaches will be examined using the computational testbed developed at the ERDC.

8357-19, Session 5

Cloud cover effects on physical soil temperatures with buried targets

Z. I. Derzko, C. D. Phan, R. M. Lydic, Jr., T. R. Moore, O. Nguyen, J. T. Broach, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Cloud cover is a major meteorological condition that affects the radiative forcing function that plays a major role in airborne detection of buried mines/IEDS with infrared sensors. This work involves the application a software application, termed ADH, that was developed at the Corps of Engineers, Engineering Research and Development Center in Vicksburg, Miss. ADH is a 3D finite element model that accounts for coupled moisture and heat transport and that is coupled to a raytracer and sensor model to form the Countermine Testbed prediction tool. The U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate coupled synthetic meteorological data to predict physical soil surface temperatures and sensor-specific apparent soil surface temperatures. This papers reports those findings as they relate to the comparison of consecutive clear days and later for consecutive cloudy days for a single geographical location. Physical and sensor-dependent apparent temperature target-background temperature predictions are presented in graphical and video form.

8357-20, Session 5

Rain effects on physical soil temperatures with buried targets

Z. I. Derzko, R. M. Lydic, Jr., C. D. Phan, T. R. Moore, O. Nguyen, J. T. Broach, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Precipitation is a major meteorological condition that affects the spectral and physical thermal properties of soils and hence plays a major role in airborne detection of buried mines/IEDS with infrared sensors. This work involves the application of a software application, termed ADH, that was developed at the Corps of Engineers, Engineering Research and Development Center in Vicksburg, Miss. ADH is a 3D finite element model that accounts for coupled moisture and heat transport and that is coupled to a raytracer and sensor model to form the Countermine Testbed prediction tool. The U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate coupled synthetic meteorological data to predict physical soil surface temperatures and sensor-specific apparent soil surface temperatures. This papers reports those findings as they relate to the effects of precipitation on infrared mine/IED detection for a single geographical location. Physical and sensor-dependent apparent temperature target-background temperature predictions are presented in graphical and video form.

8357-21, Session 5

Schedule optimization of IR detection with buried targets

Z. I. Derzko, U.S. Army Night Vision & Electronic Sensors Directorate (United States); J. Eylander, U.S. Army Engineer Research and Development Ctr. (United States); J. T. Broach, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Schedule optimization of air platforms for carrying infrared sensors for buried mine/IED detection is a high priority 1) because of the time sensitive nature of infrared detection of buried mines, 2) because of limited air platform assets, and 3) because of limited band-width for live-feed video from UAVs. Scheduling optimization for airborne detection of buried mines depends on transient meteorological predictions, transient soil properties, target and target depth. This work involves the application of a software application, termed ADH, that was developed at the Corps of Engineers, Engineering Research and Development Center in Vicksburg, Miss. ADH is a 3D finite element model that accounts for coupled moisture and heat transport and is coupled to a raytracer and sensor model to form the Countermine Testbed prediction tool. The U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate coupled the Countermine Testbed with meteorological predictions from the Weather Research Forecaster (WRF) model to predict a continuous 2-day optimized schedule for airborne mine detection, which allows for optimization of advance scheduling of appropriate air assets and bandwidth. In this paper, a continuous 2-day air asset/bandwidth schedule optimization for buried mine detection is demonstrated for a single geographic location. Physical and sensor-dependent apparent temperature target-background temperature predictions are presented in graphical and video form.

8357-22, Session 6

The evaluation hyperspectral imaging for the detection of person-borne threat objects over the 400nm to 1700nm spectral region

D. W. Allen, C. Cooksey, J. E. Neira, National Institute of Standards and Technology (United States)

The detection of person-borne threat objects, such as improvised explosive devices, at a safe distance is an ongoing challenge. While much attention has been given to other parts of the electromagnetic spectrum, very little is known about what potential exists to detect clothing obscured threats over the ultraviolet through the shortwave-infrared spectral region. Hyperspectral imaging may provide a greater ability to discriminate between target and non-target by using the full spectrum. This study investigates this potential by the collection and analysis of hyperspectral images of obscured proxy threat objects. A standard test setup and performance model will be described for consideration in use of evaluating current and future imaging technologies.

8357-23, Session 6

Role of moisture and density of sand for microwave enhancement of thermal detection of buried mines

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The main disadvantage of applying the IRT method is presence of plenty false indications in thermograms. A simple use of IRT equipment with better temperature resolution would not help in distinguishing the mines, since noise comes not from a camera, but from soil surface. Recognizing the role of moisture and density of sand and possibilities to express it quantitatively plays an important role. In our model of thermal properties of the soil the volumetric unit of the soil consists of mineral and organic particles, as well as water and air. All needed parameters can be calculated. Calculations of thermal signatures of the underground objects were made basing on 3D-heat equation for the sinus type heating of 3D model and cooling by convection. Measurements were made for field and laboratory stand-ups, using methodologies typical for "single-shot" measurements as well as analyses of transient processes based on sequence of thermograms. Results of simulations and measurements confirm expectation that high level of "radiant noises" is caused mainly by differences in the moisture and sand density levels.

8357-24, Session 6

Buried mine detection using fractal geometry analysis to the LWIR successive line scan data image

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We have engaged in research on buried mine/IED detection by remote sensing method at a safety distance using LWIR camera mounted on a moving ground vehicle. An IR image of a ground, containing buried objects can be assumed as a superimposed pattern including thermal scattering which may depend on the ground surface roughness, vegetation canopy, and effect of the sun light, and radiation due to various heat interaction caused by differences in specific heat, size, and buried depth of the objects and local temperature of their surrounding environment. In this cumbersome environment, we introduce fractal geometry for analyzing the intensity variations of scanned line data in the azimuth direction extracted from a IR image. Clutter patterns due to these complex elements have oftentimes low ordered fractal dimension of Hausdorff Dimension. On the other hand, the target patterns have its tendency of obtaining higher ordered fractal dimension in terms of Information Dimension. Random Shuffle Surrogate method and Fourier Transform Surrogate method are used to verify fractional characteristics by applying shuffle of time sequence data. Fractal interpolation to each line scan is also applied to improve the signal processing performance in order to evade zero division and enhance information of data. Some results of target extraction by using relationship between low and high ordered fractal dimension are to be presented.

8357-25, Session 7

Three-dimensional material identification and hazard detection with shortwave, infrared, supercontinuum-based spectral ladar

M. A. Powers, General Dynamics Robotic Systems (United States)

We present new experimental results from a prototype Spectral LADAR, which combines active multispectral and 3D time-of-flight point cloud imaging. The physical domain unification of these imaging modalities based on a pulse modulated supercontinuum source enables substantially higher fidelity images of obscured targets compared to the data domain fusion of passive hyperspectral cameras and conventional LADAR imagers. Spectral LADAR produces 3D spectral point clouds with unambiguously associated 3D image points and spectral vectors, promoting improved object classification performance in cluttered scenes. The 3D shape and material spectral signature of objects may be acquired in daylight or darkness, behind common glass, and behind obscurants like foliage and camouflage.

These capabilities are demonstrated by data obtained from test scenes. These scenes include plastic mine-like objects obscured by foliage, distinction of hazardous explosives inside plastic containers versus innocuous decoy materials, and 3D spectral imaging behind ordinary glass windows. These scenes, at effective ranges of approximately 45 meters, are imaged with nanosecond-regime optical pulses spanning 1080 nm to 1620 nm divided into 25 independently ranged spectral bands. The resultant point cloud is spectrally classified according to material type.

In contrast to other active spectral imaging techniques, Spectral LADAR is well suited to operate at high pixel and frame rates and at considerable stand-off distances. We discuss how its attributes, including eye safe wavelengths, relatively small apertures, and very short (single pulse) receiver integration time, bear the potential for this technique to be used on robotic platforms for on-the-move imaging and high area coverage rates.

8357-26, Session 7

Road detection and buried object detection in elevated EO/IR imagery

L. Kennedy, M. P. Kolba, J. R. Walters, Signal Innovations Group, Inc. (United States)

To assist the warfighter in visually identifying potentially dangerous roadside objects, the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) has developed an elevated video sensor system testbed for data collection. This system provides color and mid-wave infrared (MWIR) imagery. Signal Innovations Group (SIG) has developed an automated processing capability that detects the road within the sensor field of view and identifies potentially threatening buried objects within the detected road. The road detection algorithm leverages system metadata to project the collected imagery onto a flat ground plane, allowing for more accurate detection of the road as well as the direct specification of realistic physical constraints in the shape of the detected road. Once the road has been detected in an image frame, a buried object detection algorithm is applied to search for threatening objects within the detected road space. The buried object detection algorithm leverages textural and pixel intensity-based features

to detect potential anomalies and then classifies them as threatening or non-threatening objects. Both the road detection and the buried object detection algorithms have been developed to facilitate their implementation in real-time in the NVESD system.

8357-27, Session 7

Anomaly detection ensemble fusion for buried explosive material detection in forward looking infrared imaging for addressing diurnal temperature variation

D. T. Anderson, Mississippi State Univ. (United States); K. E. Stone, J. M. Keller, Univ. of Missouri-Columbia (United States); J. Rose, Mississippi State Univ. (United States)

In prior work, we presented multiple image space anomaly detection strategies for the identification of buried explosive materials in forward looking long wave infrared (LWIR) imagery. Herein, we extend that work and focus on the robust recognition of targets in light of diurnal temperature variation. First, an ensemble of shape and size independent image space anomaly detection algorithms based on Gaussian mixture models and maximally stable extremal regions is discussed. Focus is then placed on measuring individual detector accuracy. These accuracies are used to learn and subsequently fuse the ensemble in a temporally aggregated (multi-look/frame) discrete Universal Transverse Mercator (UTM) space. The fused result is then subject to an ensemble of size contrast detectors, mean shift clustering and it is combined with image space cell-structured features and support vector-based classification. Experimental results are shown based on field data measurements from a US Army test site.

8357-28, Session 7

Standoff detection and identification of powders and gaseous chemicals using hyperspectral imaging

J. Gagnon, S. Savary, V. Farley, M. Chamberland, Telops (Canada)

Standoff detection of solid powders and gaseous chemicals based on their spectral signature is a key asset for defense and security applications.

The Telops Hyper-Cam sensor is an imaging spectrometer that enables the spatial and spectral analysis of targets. It is based on the Fourier-transform technology yielding high spectral resolution and enabling high accuracy radiometric calibration. It provides datacubes of up to 320x256 pixels at spectral resolutions as fine as 0.25 cm-1. The LWIR version covers the 8 to 11.8 µm spectral range.

The Hyper-Cam has been recently used for the standoff detection and identification of targets including ammonium sulphate powder as well as methanol and acetone gaseous emissions. These new detection and identification results, based on the spectral signature of the targets, are presented in this paper.

8357-29, Session 8

Improved thermal neutron activation sensor for detection of bulk explosives

J. E. McFee, A. A. Faust, Defence Research and Development Canada, Suffield (Canada); H. R. Andrews, T. Clifford, Bubble Technology Industries, Inc. (Canada); C. Mosquera, Defence Research and Development Canada, Suffield (Canada)

Defence R&D Canada Suffield and Bubble Technology Industries have been developing thermal neutron activation (TNA) sensors for detection of buried bulk explosives since 1994. First generation sensors, employing an isotopic source and NaI(Tl) gamma ray detectors, were deployed by Canadian Forces in 2002 as confirmation sensors on the ILDS teleoperated, vehicle-mounted, multi-sensor anti-tank (AT) landmine detection systems. The first generation TNA could detect anti-tank mines buried 10 cm or less in no more than a minute, but deeper mines and those significantly displaced horizontally required considerably longer times. Mines as deep as 30 cm could be detected with long counting times (1000 s). The latest generation TNA detector has been developed with a number of improvements aimed at increasing sensitivity and facilitating ease of operation. Among these are an electronic neutron generator to increase sensitivity for deeper and horizontally displaced explosives; LaBr3(Ce) scintillators, to improve time response and energy resolution; improved thermal and electronic stability; improved sensor head geometry to minimize spatial response non uniformity; and more robust data processing. This improved sensitivity can translate to either decreased counting times, decreased minimum detectable explosive quantities, increased maximum sensor-to-target displacement or a tradeoff among all three. Experiments to determine the performance of the latest generation TNA in detecting buried landmines were conducted in Spring 2011. This paper will describe the latest generation system. The experimental setup and methodology will be detailed and preliminary comparisons between the performance of first and latest generation systems will be presented.

8357-30, Session 8

Detection of bulk explosives in culverts using thermal neutron activation

A. A. Faust, J. E. McFee, C. Mosquera, Defence Research and Development Canada, Suffield (Canada); T. Clifford, H. R. Andrews, A. Shinn, Bubble Technology Industries, Inc. (Canada)

Bulk explosives, such as improvised explosive devices (IEDs), hidden in culverts are a serious threat to the Canadian Army. Even though the quantity of explosives can be large, detection is challenging because of the large separation between detector and target. Defence R&D Canada - Suffield and Bubble Technology Industries have been developing thermal neutron activation (TNA) sensors for detection of buried bulk explosives for over 15 years. First generation sensors, using an isotopic source and NaI(Tl) gamma ray detectors, were deployed by Canadian Forces in 2002 as confirmation sensors on the ILDS teleoperated, vehicle-mounted, multi-sensor anti-tank (AT) landmine detection systems. The first generation TNA could detect anti-tank mines buried 10 cm or less in roughly a minute or less and mines as deep as 30 cm could be detected for long count times (1000 s). The latest generation detector under development has an electronic neutron generator, LaBr3(Ce) scintillators, increased stability, improved sensor head geometry and robust data processing which all help to provide improved sensitivity. This improved performance enables increased sensor-to-target distances, making it potentially feasible to detect large improvised explosive devices in culverts. Experiments to determine the ability of the next generation TNA to detect IEDs in culverts were conducted in Spring 2011. This paper will describe the experimental equipment, setup and methodology. Results, including preliminary estimates of maximum detector-to-target standoff for typical threat quantities of explosives, will be presented.

8357-31, Session 8

Pixelated diffraction signatures for explosive detection

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Energy dispersive X-ray diffraction (EDXRD) is a technique which can

be used to improve the detection and characterisation of explosive materials. This study has performed EDXRD measurements of various explosive compounds using a novel, X-ray sensitive, pixelated, energy resolving detector developed at the Rutherford Appleton Laboratory, UK (RAL). EDXRD measurements are normally performed at a fixed scattering angle, but the 80x80 pixel detector makes it possible collect both spatially resolved and energy resolved data simultaneously. The different detector materials used are Cadmium Telluride (CdTe) and Cadmium Zinc Telluride (CZT). These detectors can be utilised at room temperature and give excellent spectral resolution. The setup uses characteristics from both energy dispersive and angular dispersive scattering techniques to optimise specificity and speed.

The purpose of the study is to develop X-ray pattern "footprints" of explosive materials based on spatial and energy resolved diffraction data, which can then be used for the identification of such materials hidden inside packages or baggage. The RAL detector is the first energy resolving pixelated detector capable of providing 1 keV spectroscopy at energies up to 150 keV. The benefit of using this device in a baggage scanner would be the provision of highly specific signatures to a range of explosive materials.

We have measured diffraction profiles of five explosives and 14 other materials that might be found in carry-on baggage. High resolution, high count spectra have been obtained and the results subjected to multivariate analysis. Results will be presented to show the specificity of the technique in finding explosives within baggage.

8357-32, Session 8

Steady state free precession (SSFP) sequence compared to one-pulse sequence for RDX detection at 5.192 MHz

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Nuclear Quadrupole Resonance (NQR) is a promising technique for detection of illicit substances (1). NQR is a radio frequency (RF) spectroscopy and signals can be observed from nuclei that possess an electric quadrupole moment Q. RF radiation excites transitions between energy levels that are split by the interaction of Q with an electric field gradient arising from the electric charge distribution surrounding the nucleus. The amount of this splitting is determined by molecular and crystal parameters and provides a highly specific fingerprint of different substances and their possible modifications. Explosives, narcotics or counterfeit medicines contain quadrupolar nuclei and this provides a way to use NQR for non-invasive detection of these substances.

In the basic NQR experiment i.e a one-pulse sequence (OP), the signal is induced by a single RF pulse. Because of its small amplitude, the signal is enhanced by averaging several measurements. However the excitation cannot be repeated until the system of spins has recovered and this recovery depends on the spin-lattice relaxation time (T1). Provided that T1 is short, it is possible to obtain signals at a repetition rate much higher than 1/T1 with the Steady State Free Precession (SSFP) sequence. It has been claimed that the SSFP is a more efficient acquisition sequence than the OP. The present study will show using simulations (2) and experimental data that SSFP is a useful sequence for RDX measurements at 5.192 MHz but is not superior to the basic OP with a repetition rate smaller than 1/T1.

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8357-33, Session 8

Novel approaches in nuclear magnetic/ quadrupole resonance techniques for explosives detection

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Nuclear Quadrupole Resonance (NQR) and Nuclear Magnetic Resonance (NMR) are very prospective methods of the bulk detection of explosives and illicit substances. Both techniques are very close to each other technically and could be applied simultaneously. Our work presents recent developments in the NQR, NMR and double resonance (NMR/NQR or NQR/NQR) methods as well as magnetic resonance imaging (MRI) techniques.

The experimental studies were performed using Tecmag Apollo/Redstone NMR/NQR console in combination with Tomco pulse amplifiers, home-made preamplifiers, Q-spoilers and probes. We also used low-field (0.6 T) MRI device developed at KPhTI for imaging experiments with liquid containers. The experimental studies of NMR relaxation parameters were performed using a pulsed NMR spectrometer BRUKER Avance 400.

NQR studies revealed that detection of solid state explosives with high resonance frequencies is feasible, while the detection of TNT is still very challenging issue. Novel approaches and advanced sensors are needed to resolve the issue of reliable detection of low-frequency solid explosives. Multifrequency and double NMR/NQR methods are prospective approaches in this respect. Application of these methods however is strongly linked to a specific substance to be detected.

On the other hand, various liquids can be detected using low magnetic field NMR. We shown that reliable discrimination among extended set of liquids reveal a need in use of additional NMR parameters or complimentary techniques. Application of MRI methods in various imaging modes (T1 , T2 or diffusion weighted) is demonstrated to be a feasible method of explosive/illicit liquids detection for aviation security.

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8357-84, Poster Session

Improving the detection range via correlation of long PN codes

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This paper proposes an active stimulation and correlation method for detecting super-regenerative radio frequency (RF) receivers. Long pseudo noise (PN) sequences are used as the stimulation signals. High correlation between known PN sequence and stimulated unintended emissions from RF receivers helps improving the detection range. The detection distance is much larger compared to passive detection method and power detection method. RF receivers generate unintended emissions from the nonlinear devices. The power of these unintended emissions is usually smaller than a threshold, e.g., –70dBm, as per the FCC regulations. Direct detection (passive detection) of these emissions is a challenging task especially in noisy conditions. When a stimulation signal is applied, super-regenerative receivers generate unintended emissions that contain the stimulation signal and its harmonics. One of the stronger emissions can be used to extract the stimulation signal for correlation. Excellent correlation property of PN sequence enables us to improve the range and accuracy of detecting the super-regenerative receivers through stimulation method even in noisy conditions. The experiment involves detection of wireless doorbell, a commercially available super-regenerative receiver. Universal Software Radio Peripheral (USRP) is used for transmitting the stimulation signal and receiving unintended stimulated emissions from the doorbell. The generation of stimulation signal and processing of the received signal is done in MATLAB/Simulink. PN sequence is converted to On-Off Keying (OOK) baseband modulated signal and is modulated on a radio frequency carrier for transmission. Experiments show that the detection range of the proposed method with long PN sequences is much larger as compared to passive detection and power detection methods.

8357-34, Session 9

Landmine detection by 3D GPR system

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Tohoku University and University of Miami are collaboratively working on the application of 3DGPR for detection of buried explosive devices. Currently we are investigating the use of IGPS, a large work volume metrology method, as a complementary tracking device for the CCD camera. IGPS can provide absolute and better than centimetre precise x,y,z coordinates to multiple mine sensors at the same time. At the University of Miami we have developed a novel 3DGPR system for efficient and high-resolution 3D shallow subsurface scanning of larger areas (25 m2 to thousands of square meters) with irregular topography . Field test by using 500MHz GPR system equipped with 3DGPR system was conducted. PMN-2 and Type 72 mine models have been buried at the depth of 5-20cm. We could demonstrate that the 3DGPR can visualize each of these buried land mines very clearly.

8357-35, Session 9

GPR hardware performance baseline

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In this paper we present a series of test procedures and metrics to characterize the performance of an arbitrary stepped-frequency ground penetrating radar (GPR) with multi-channel antenna array. These techniques are intended to evaluate innate hardware performance as it is relevant to the imaging and detection of buried threats in an operational scenario. These procedures probe both the free-space and standard target response of the system. The time-varying nature of the system response is included in order to understand and characterize “warm-up” time as it is relevant for operational missions. The procedures and metrics are expected to characterize how well the direct coupling is suppressed (either directly in hardware or in conjunction with conventional subtractive techniques) as well as the inherent susceptibility to electromagnetic interference. The nature of the synthesized pulse from the stepped-frequency GPR and the resulting temporal resolution is also considered. These methods and metrics are applied to three different stepped-frequency GPR systems, including two variants of a commercial-off-the-shelf GPR originally designed for roadway inspection and utility mapping as well as a custom GPR system designed for real-time detection of buried explosive hazards.

8357-36, Session 9

Modeling GPR data from lidar soil surface profile

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Ground Penetrating Radar (GPR) has been applied for several years to the problem of detecting both anti-personnel and anti-tank landmines. One major challenge for reliable mine detection using GPR is removing the response from the ground. When the ground is flat this is a straightforward process. For the NIITEK GPR, the flat ground will show up as one of the largest responses and will be consistent across all the channels, making the surface simple to detect and remove. Typically, the largest responses from each channel, assumed to be the surface, are aligned in range and then zeroed out. When the ground is not flat, the response from the ground becomes more complicated making it no longer possible to just assume the largest response is from the ground. Also, certain soil surface features can create responses that look very similar to those of mines. To further complicate the ground removal process, the motion of the GPR antenna is not measured, making it impossible to determine if the ground or antenna is moving from just the GPR data. To address surface clutter issues arising from uneven ground, NVESD investigated profiling the soil surface with a LIDAR. The motion of both the LIDAR and GPR was tracked so the relative locations could be determined. Using the LIDAR soil surface profile, GPR data was modeled using a simplified version of the Physical Optics model. This modeled data could then be subtracted away from the measured GPR data, leaving the response without the soil surface.

In this paper we present a description and results from an experiment conducted with a NIITEK GPR and LIDAR over surface features and buried landmines. A description of the model used to generate the GPR response from the soil and the algorithm that was used to subtract the two is provided. Mine detection performances using both GPR only and GPR with LIDAR algorithms are compared.

8357-37, Session 9

Forward looking GPR sidelobe reduction using L1-norm minimization

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Ground Penetrating Radar (GPR) has been applied for several years to the problem of detecting both anti-personnel and anti-tank landmines. One area of research is using Forward Looking GPR (FLGPR) to detect mines. While FLGPR has the advantage of standoff versus downward looking GPR, the responses from buried targets generally decrease while the responses from clutter increase. One source of clutter is from sidelobes and grating lobes caused by off-road clutter. As it is not possible to get a narrow beamwidth at the low frequencies required to get ground penetration, FLGPR receives responses from both on and off the road. Off-road clutter responses are often much stronger than the responses from buried mines. These off-road clutter objects can produce sidelobes that overlap with and obscure the responses from in-road targets. This becomes especially problematic if the antenna array spacing is not fine enough and grating lobes are formed. To reduce both the sidelobes and grating lobes, a technique using L1-norm minimization was tested. One advantage of this technique is it only requires a single aperture. The resulting image retains phase information which allows the images to be then coherently summed, resulting in better quality images. In this paper a description of the algorithm is provided. The algorithm was applied to a FLGPR data set to show its ability to reduce both sidelobes and grating lobes. Resulting images are shown.

8357-38, Session 9

A novel forward and backward scattering wave measurement system for optimizing GPR standoff mine/IED detector

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We have been engaging in developing standoff mine/IED detectors by using ground penetrating radars (GPRs) which has been widely used for mine/IED detectors for its advantages in regard to safety and efficiency. However, since the reflected signals from buried targets are often disturbed by clutter signals from ground surface with various roughness, especially at lower depression angle which corresponds to the safer or longer distance. Therefore, understanding of the forward

and backward scattering wave from buried targets and those from ground with different surface roughness are essential for improving GPR signal processing to obtain a better performance for standoff detection capability. For this reason, we made a measurement system by installing fundamental apparatus in an anechoic chamber with a soil container to realize the more quantitative analysis in the controlled soil condition. The fundamental apparatus consists of a UWB radar and the spherical positioner to automatically control both the transmitting angle and the receiving angle independently. In experiments, the reflected signals from the buried simulant anti tank mine, the simulant projectile, and those from the ground at different surface roughness are extracted, and the forward and backward scattering wave from the targets are obtained as a function of depression angle of the antenna. In this paper, the measurement system and these experimental results will be described. These fundamental data will be used for improving the standoff detection capability. Moreover the scattering wave from various buried targets will be figured out by using this measurement system.

8357-39, Session 9

Veriable focusing antenna for wireless power transmission and remote sensing in millimeter-wave wavelengths

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Abstract- The design of a cassegrain antenna with adjustable focus is descried. This antenna consist of a mmw-bend cassegrain feed requiring the sub reflector surface to be highly reflective at 94GHz. The cassegrain antenna as a near field as a function of their aperture, in the near field region we can change the size of the beam and doing a focusing as function of the sub-reflector distance and then we get the maximum power density and minimum size of the beam, the focus of the beam and the develop of this antenna is according to the Gaussian model, with this model we can find the distance between the reflector and the sub-reflector and then we get the focus as function of the distance. This design is good for many application in the mmw region like imaging radar, spectroscopy and power transmission. Beside of the cassegrain antenna there is a system of motors that move the sub-reflector until we get the maximum power density on the selected distance. In this paper we present the development of the quasi optical system, simulation and experiment results.

8357-40, Session 10

X-ray backscatter imaging of pressure-plate improvised explosive devices

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Improvised Explosive Devices (IEDs) in the form of pressure-plates are a serious threat in current theatres of operation. X-ray backscatter imaging (XBI) is a potential method for detecting buried pressure-plates (PPs). In particular, the detection of low-metal content PPs with XBI is an attractive method since the often-used metal detectors cannot detect those. XBI has been studied previously for humanitarian demining with limited success; however PPs have other characteristics than traditional anti-personnel mines making XBI a viable technique against PPs.

Monte-Carlo simulation code was developed in-house and has been used to study the potential of XBI for pressure-plate detection. The model was validated using results from previous landmine detection trials. Though only a superficial comparison could be made with the experiments, the model is believed to be accurate enough. Here, it has to be realised that X-ray scattering has a well established theory which is also relatively simple with accurate physical parameters. In addition, independent simulations from the XBI-company AS&E confirm the NC3A simulations.

Simulated results of X-ray backscatter images from a buried pressure plate show that there is enough contrast for detection at 5 cm but not at 10 cm depth. Increasing the photon energy does not improve the soil penetration due to the reduction of photon energy after scattering. The resolution of these images is quite low due to the multiple scattering at 350 keV. For pressure-plate detection, this is not a big drawback since these devices are relatively large. Scanning speeds will be in the wide range of 1 to 10 km/h. X-ray backscatter imaging seems to be a viable technique for detection of pressure-plates that are not buried too deep.

8357-41, Session 10

The use of laser-induced x-rays for detection and imaging

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The development of multi-terawatt peak power lasers based on chirped pulse amplification has allowed the phenomenon of laser induced electron acceleration to be demonstrated. Ultra-high peak power lasers are able to produce much higher accelerating fields than traditional radio frequency (RF) electron accelerators and can therefore be far more compact. Ultra-short pulse lasers that have table top footprints can accelerate electrons to relativistic energies through interactions with matter. These laser induced relativistic electrons can then be used to produce ionising radiation via bremsstrahlung, synchrotron motion or scattering. The potential of laser produced X-rays and gamma rays to improve upon conventional X-/gamma ray backscatter detection and imaging of concealed targets is investigated. The ability of laser induced ionising radiation to improve upon stand-off distance, resolution and penetration over more conventional techniques using ionising radiation is given particular attention. Comparisons are also made between laser induced bremsstrahlung radiation using low and high atomic number materials as targets. Experimental data of laser induced ionising radiation has been acquired using the Vulcan laser at the Central Laser Facility at the Rutherford Appleton Laboratory and an analysis of this data is presented. Propagation of ultra-high peak power lasers in air is also considered, with respect to defocusing mechanisms such as ionisation and self focusing mechanisms such as the Kerr effect.

8357-42, Session 10

Laser neutralization of surface and buried munitions

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This report describes the results of an on-going program to develop laser technology for rapid neutralization of buried mines and mine-like targets from a safe standoff distance. The primary objective of this program is to demonstrate, via field experiments, the capabilities of a breadboard laser system to “drill” through overburden to defeat buried explosive ordnance at standoff distances. This report discusses results of field testing done with a 10 kW single mode laser at a standoff distance of 50 meters.

8357-44, Session 10

Design and construction of a proton magnetometer for detection of metals

N. Ramirez, Univ. EAFIT (Colombia)

The generation of instrumentation to able of carrying out the measurement of magnetic fields of very low intensity, near to the order of nano-tesla, is currently used in many applications, from the generation of aeromagnetic maps for the oil finding and deposits in sedimentary rocks until applications for to study a day and night variations of the geomagnetic field. Additionally archaeological exploration applications and gravity and metal detection between others. For these reasons, I proposed in this paper to present the research and developed of design and construction of a proton precession magnetometer for measuring magnetic fields of low intensities similar to those generated by the geomagnetic field, a quality that allow to engineers measuring of detection of metal between others

8357-45, Session 11

ALIS deployment in Cambodia

M. Sato, K. Takahashi, Tohoku Univ. (Japan)

Conventional landmine detection depends on highly trained and focussed human operators manually sweeping 1m2 plots with a metal detector and listening for characteristic audio signals indicating the presence of AP landmines. We are in the process of developing a high-resolution landmine scanning system which produces horizontal slices of the shallow subsurface for visualization of buried explosives and inert clutter. As many AP mines contain minimum amounts of metal, metal detectors need to be combined with a complimentary subsurface imaging sensor. Ground Penetrating Radar (GPR) is widely accepted for subsurface sensing in the fields of geology, archaeology and utility detection. The demining application requires real-time imaging results with centimetre resolution in a highly portable package. The key requirement for sharp images of the subsurface is the precise tracking of the geophysical sensor(s) during data collection. We should also notice that GPR system is a very wide band radar system, and equivalent to UWB radar, which has recently been developed for short-range high-accuracy radar. We are currently testing a dual sensor ALIS which is a real-time sensor tracking system based on a CCD camera and image processing. In this paper we introduce the GPR systems which we have developed for detection of buried antipersonnel mines and small size explosives. ALIS has been deployed in Cambodia since 2009 and detected many mines in mine fields. We also report the current status of ALIS in Cambodia.

8357-46, Session 11

Investigation of the effects of operator technique on handheld sensor data for landmine detection

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Ground penetrating radar (GPR) is a commonly employed sensing modality for landmine detection. It has been successfully deployed in vehicular systems, and is also being integrating into handheld systems. Handheld mine detection systems are typically deployed in situations where either the terrain or mission renders a vehicular-based system less effective.

Handheld systems are often more compact and maneuverable, but quality of the sensor data may also be more dependent on the operators experience with and technique in using the system. In particular, the sensor height with respect to the air-ground interface may be more variable than with a vehicular-based system. This variation in sensor height above the air-ground interface may have the potential to adversely affect mine detection performance withthe GPR sensing modality.

In this work, the effects of operator technique on handheld sensor data quality is investigated, and ground alignment is explored as a potential approach to reducing variability in the sensor data quality due to operator technique. Results for data measured with a standard GPR/EMI handheld sensor at a standardized test site are presented.

8357-48, Session 12

On the evaluation and improvement of spectral features for the detection of buried explosive hazards using forward-looking, ground-penetrating radar

J. W. Farrell, T. C. Havens, D. K. Ho, J. M. Keller, Univ. of Missouri-Columbia (United States); T. T. Ton, D. C. Wong, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Soumekh, Univ. at Buffalo (United States)

Forward looking ground penetrating radar (FLGPR) is a viable technology for the detection of buried explosives that enables comfortable standoff distance. The detection task, however, is very challenging because of the low radar signal return strength, the lack of depth information and inadequate spatial resolution. Detection through the frequency domain spectral features has previously been shown to be effective in improving performance. This paper compares the performance using 1-D and 2-D spectral features and provides enhancements in the features to better detect the buried explosives. Results based on actual field data show that the 2-D spectral features yield better detection of explosive hazards than the 1-D spectral features. Furthermore, the performance of spectral features using different classifiers, such as modified k-nearest neighbor (k-NN) classifier and support vector machine (SVM), will be contrasted. The experimental results using the data collected at an US Army test site show the effectiveness of spectrum based features in the detection of explosive hazards.

8357-49, Session 12

Multiple outlook learning for explosive hazard detection in forward-looking ground-penetrating radar

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This paper proposes an effective anomaly detection algorithm for a forward-looking ground-penetrating radar (FLGPR). The challenges in detecting explosive hazards with FLGPR are that there are multiple types of targets buried at different depths in a highly-cluttered environment. A wide array of target and clutter signatures exist, which makes classifier design difficult. Recent work in this application has focused on fusing the classifier results from multiple frequency sub-band images. Each sub-band classifier is trained on suites of image features, such as Gabor filters and local binary patterns (LBP). This prior work fused the sub-band classifiers by, first, choosing the top-ranked feature at each frequency sub-band in the training data and then accumulating the sub-band results in a confidence map. We extend this method by employing multiple outlook learning for feature-level fusion. Multiple outlook learning maps each outlook (feature space) onto a target outlook by matching the statistical properties of all the training data features. With this method, we are able to utilize the entire suite of features for anomaly detection, not just the top-ranked feature. Using FLGPR data collected at a US Army test site, we show that classifiers trained using multiple outlook learning show better explosive hazard detection capabilities than existing methods.

8357-50, Session 12

An automatic detection system for buried explosive hazards in FL-LWIR and FL-GPR data

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Improvements to an automatic detection system for locating buried explosive hazards in forward-looking long-wave infrared (FL-LWIR) imagery, as well as the system's application to detection in confidence maps and forward-looking ground penetrating radar (FL-GPR) data, are discussed. The detection system, described in previous work, utilizes an ensemble of trainable size-contrast filters and the mean-shift algorithm in Universal Transverse Mercator (UTM) coordinates. Improvements of the raw detection algorithm include weighted mean-shift within the individual size-contrast filters and a secondary classification step which exacts cell structured image space features, including local binary patterns (LBP), histogram of oriented gradients (HOG), and maximally stable extremal regions (MSER) segmentation based shape information, from one or more looks and classifies the resulting feature vector using a support vector machine (SVM). FL-LWIR specific improvements include replacement of a static road mask by an automatic road segmentation algorithm and elimination of the need for multiple models due to diurnal temperature variation. The improved algorithm is assessed on FL-LWIR and FL-GPR data from recent collections at a US Army test site.

8357-51, Session 12

Enhanced buried object detection using fusion of UHF-SAR detections and lidar elevation information

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It is well recognized that UHF SAR has limited ground penetration capabilities. However, detection using SAR-only data often results in considerable above-ground false alarms due to registration error, scaling, misalignment, displacement or movement of above-ground objects. In this paper, we propose to utilize LIDAR elevation information at the UHF-SAR detections to eliminate the above-ground false-alarms to isolate the buried IEDs in the process. The information obtained from two different classes of sensors complement each other to locate buried objects with improved precision. First, Anomaly Detection is applied to1-pass UHF-SAR data to detect the targets plus false-alarms. Then LIDAR elevations at the detected locations are used to rule out the false alarms produced by the above ground objects that are at higher elevation than the buried objects. The proposed SAR-LIDAR integration strategy is shown to detect emplaced buried objects with an order of magnitude improvement in detection performance, i.e., achieve higher PD at lower PFA when compared with SAR-only performance. The proof-of-concept research was conducted under an Air Force SBIR Phase I (Topic: AF093-139), and is demonstrated on simultaneous multisensor UHF-SAR/LIDAR data collected under JIEDDO's HALITE-1 program.

8357-52, Session 13

Optimizing a lab-on-a-fiber optic device for trace TNT explosive detection

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In our earlier work, we proposed the concept of lab-on-a-fiber (LOF) and demonstrated a high performance device based on this concept for trace TNT explosive detection, which showed 30% fluorescence quenching within 10 seconds [1,2]. The device occupies only a space of 1.6 x 1.6 x 0.8 mm, Nevertheless, we found it could be further improved to enable not only a smaller device, but also a low-cost system with easy fiber replacement and maintenance. The smaller size LOF device is particularly important when connecting it with the explosive vapor pre-concentration unit [2]. For a fluorescence quenching based LOF, the major challenge is to maximize the fluorescent signal collection from a minimum LOF device and minimize the return excitation power. We found that the 400 um core fiber with a taper-film overlay at one end fulfills the aforementioned requirements. Its un-tapered end is simply connected with a bifurcated fiber bundle with the SMA connection whose two fiber leads are respectively for excitation light delivery and fluorescent light collection, both of which have the SMA connection as well. The fiber taper also enables a longer transmission distance for remote monitoring purpose. After all these efforts, the improved LOF device occupies only a 0.4mm x 1 mm space and preserves the quenching efficiency reported before. This tapered fiber segment could be arbitrarily short (< 50 mm long, for instance), allowing easy connection and removal from the pre-concentration unit. The bifurcated fiber bundle could be arbitrarily long allowing for remote detection and is re-usable.

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8357-53, Session 13

Explosives particle detection using multispectral imaging Raman spectroscopy

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Multispectral imaging Raman spectroscopy is a new technique for detecting and identifying explosive residues, e.g. explosives particles that will be left on different surfaces after manufacturing and handling explosive devices.

By imaging a suspect surface using the imaging Raman technique, explosive particles at stand-of distances can be identified and displayed using color coding [Henric Östmark, Markus Nordberg, and Torgny E. Carlsson, "Stand-off detection of explosives particles by multispectral imaging Raman spectroscopy," Appl. Opt. 50, 5592-5599 (2011)].

The limit of detection for the imaging Raman spectroscopy system has been determined, by measuring particle residues of 2,4,6-trinitrotoulene (TNT), 2,4-dinitrotoulene (DNT), ammonium nitrate (AN) and cyclotrimethylenetrinitramine (RDX). The detection system was equipped with a green second harmonic Nd:YAG laser and an eight inch telescope. The distance to the target was 10 m and the imaged area was 25 mm × 25 mm for each measurement. The measured multi spectra data cubes were evaluated using least square fitting to determine the detection limit.

In many civilian applications an eye- and skin-safe detection system would be preferable. Therefore, in order to use an imaging Raman detection system in a real system with people in the vicinity the system has been redesigned to use an ultra violet laser. Here will be presented an ultra violet imaging Raman system. It uses a pulsed solid state laser at 355 nm with low pulse energy and high repetition rate in order to be skin-safe, eye-safe and invisible for the human eye.

8357-54, Session 13

Time-of-flight mass spectrometry for explosives trace detection

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The evolving global terrorist threat in combination with increased travelling requires improved methods for efficient identification of explosives at e.g. security checkpoints. This work presents a sensitive and selective trace detection technology based on single-photon laser ionization time-of-flight mass-spectrometry (SPI-ToFMS). The system is primarily developed for use at automated border controls for screening of vehicles and pedestrians, but it can be adapted for other types of security checkpoints. With fast online sampling and detection the entire procedure is completed within 60 seconds, thereby maintaining a high flow of travellers. With the target of detecting ppb levels, the detector is adapted for trace amount identification of most commonly used explosives. Algorithms and user interface are developed for automatic and simple operation, with the requirement to obtain a low false alarm rate. After signal processing, the result is presented for the operator as “no alarm” or “alarm”. The vapour can optionally be concentrated before entering into the detector. An electrostatic particle concentrator is under development, optimized to enhance the sensitivity with a factor of 10. In addition, a cold trap will be manufactured to further increase the concentration. Without concentrators, measurements down to ppm levels have been performed. Resonant multi-photon ionization of explosive molecules is, due to its improved selectivity, also studied as a verification method. Recently, a mobile SPI-ToFMS prototype has been built for final demonstration in real scenarios at end users facilities. Results from our lab measurements on explosives and explosive-related substances will be presented.

8357-55, Session 13

Quantum dot material for the detection of chemicals associated with landmines, IEDs, and HME material

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Changes in the fluorescence of semiconductor nanocrystals were explored as a potential sensing mechanism for the detection of chemicals associated with landmines, IEDs and HME materials. Nanocrystals are able to participate in electron-transfer reactions as an electron donor or as an electron acceptor, with both scenarios affecting the fluorescence intensity of the nanocrystal. The ability of the nanocrystals to act as electron donors or acceptors increases the number of chemicals associated with landmines, IEDs, and HME materials that could be detected with this approach. A series of CdSe nanocrystals ranging in size from 2.1 to 5 nm, with fluorescence emissions ranging from 480 to 610 nm, were studied with the Stern-Volmer relationship and photo-excited lifetime measurements. The Stern-Volmer experiments demonstrated an increased sensitivity to electron transfer reactions with electron accepting molecules as the size of the nanocrystals decreased. The quenching constant of the smallest nanocrystal, 2.1 nm CdSe, towards 1,4-dinitrobenzene was 1784.8 M-1, while under the same experimental conditions the average quenching constants of five conjugated organic polymers was 196.5 M-1. Photo-excited lifetime measurements showed excited state lifetimes ranging from 115 ns to 28 ns for the CdSe nanocrystals, with lifetimes of the nanocrystals decreasing with the addition of 1,4-dinitrobenzene. This is in contrast to conjugated organic polymers, which exhibit average lifetimes on the order of 100s ps. The decrease in lifetime with the addition of a quencher is indicative of either a collisional quenching process, a Förster resonance energy transfer process, or a combination of the two. The increased excited state lifetimes of the nanocrystals, combined with the multiple quenching mechanisms, explain the sensitivity increase for the CdSe nanocrystals, compared to conjugated organic polymers.

8357-57, Session 13

Spectral feature selection for use in chemometrics

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This paper examines the detection capability of laser-induced breakdown spectroscopy (LIBS) for discriminating trace explosive residues on various surface materials. The high resolution, broadband spectra found in LIBS offer significant potential for target residue spectral discrimination, but it comes at a price; the plasma-induced emission spectra include constituent elements from not only the target material, but also from interfering background materials, the supporting substrate, and from the atmosphere itself. In addition, variations in the laser energy/beam profile and evidence of plasma photochemistry add further complexity to the detected emission spectra. This complexity requires the application of advanced chemo-metric algorithms to discern whether a spectrum indicates the presence of a hazardous material. Appropriate feature selection within LIBS spectra is also important to optimize algorithm processing speed and to prevent overtraining on non-critical spectral features.

Multiple sets of laboratory double-pulse LIBS spectra were collected for a small set of explosives residues deposited on metallic substrates. We then demonstrate an algorithm approach that leverages a genetic algorithm (GA) for feature selection and support vector machines (SVM) for target discrimination. The SVM approach has achieved similar performance (detection rates > 90%, false alarms < 10%) on a limited target set, when compared to other techniques such as principal component analysis (PCA) and partial least-squares discriminant analysis (PLS-DA).

8357-58, Session 14

Line matching for automatic change detection algorithm

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During foreign operations, Improvised Explosive Devices are among the major threats that soldiers may encounter along regularly used itineraries. By using a vehicle-mounted camera, we propose an approach for detecting significant changes on these routes.

Our change detection system compares two images taken from different viewpoints. One image is extracted from a reference stream of the itinerary; the other is displayed in live mode and may reveal suspicious regions. Based on image registration, our comparison can be computed by a 2D planar transformation, as a dominant plane (the ground) stands out from our outdoor image pair. Homographies are adapted to compensate for the camera global motion. However, any 3D scene point not included in the dominant plane is mismatched and is therefore regarded as a change. The change detection algorithm has to be robust to parallax phenomena caused by the viewpoint difference. Epipolar geometry takes this into account.

This paper presents a novel framework for detecting changes. According to the stereo vision theory, the epipolar constraint allows two images to be matched line by line by applying a geometric transformation called rectification. Along all the corresponding lines, intensity profiles are compared with an automatic method based on extrema matching. To consider the scale in a 3D scene, adaptive space warping is used to resample signals. When the signals are matched, changes are highlighted by a simple difference between intensity profiles.

Experiments with outdoor and indoor images containing strong parallax effects demonstrate that our approach is suitable for an operational application.

8357-59, Session 14

Change-based threat detection in urban environments with a forward-looking camera

K. D. Morton, Jr., C. R. Ratto, L. M. Collins, P. A. Torrione, Duke Univ. (United States)

Roadside explosive threats continue to pose a significant risk to soldiers and civilians in conflict areas around the world. These devices are easy to manufacture and procure, but are difficult to reliably detect using standard sensing modalities due to their ad hoc nature. Although large roadside explosive devices may be difficult to conceal in rural or desert environments, urban settings provide a much more complicated background where seemingly innocuous objects (e.g., piles of trash, roadside debris, trash cans) may pose a real threat. Since direct detection of innocuous objects would flag too many possible objects to be of use, techniques must be employed to reduce the number of alarms generated and present only a limited subset of possibly threatening objects to a user. In this work we propose the application of change detection techniques to reduce false alarm rates and increase detection capabilities for possible threat identification in urban environments. The proposed model leverages data from multiple video streams collected over the same regions by first applying video aligning and then using non-parametric mixture models to detect changes based on image keypoints in the video streams. Data collected at an urban warfare simulation range at an Eastern US test site was used to evaluate the proposed approach, and significant reductions in false alarm rates compared to simpler techniques are shown.

8357-60, Session 14

Optimized feature-detection for on-board vision-based surveillance

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Our general framework is the detection of Improvised Explosive Devices (IED) aided by image processing. Based on a comparison between the images observed by a vehicle-mounted camera and a reference video sequence taken along the same itinerary, we aim at providing assistance in the detection of potential threats.

One of the key steps of such systems is the registration of two images of the same scene taken at different times, and hence from slightly different viewpoints and with varying illumination. This registration relies on the detection of features that can be robustly matched between images.

A wide variety of feature detectors have been proposed, such as the now-standard Harris, SIFT or SURF detectors. Most of these algorithms require, as a preliminary step, the tuning of some parameters which usually control the number, the robustness and the coverage of the features over the image and which strongly depend on the imaging conditions (nature of the scene, illumination, camera settings, etc.). Specifically, the registration of the road plane, and therefore the number of detected key-points in this region, is here of crucial importance.

Relying on a detailed quantitative evaluation of the most popular feature detectors on representative image sequences, we study the influence of these parameters on the system performances, and explore the possibility of their automatic adjustment. A solution to this rarely-addressed problem would provide a control over the feature distribution, avoiding the end-user to tailor the system parameters to the imaging conditions, and lead to a significant performance improvement.

8357-61, Session 14

Processing forward-looking data for anomaly detection: single-look, multi-look, and spatial classification

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Many effective buried threat detection systems rely on close proximity and near-vertical deployment over subsurface objects before reasonable performance is obtained. A forward-looking sensor configuration, where an object can potentially be detected from much greater distances, would allow for safer detection of explosive threats, and increased rates of advance. Forward-looking configurations also provide an additional advantage of yielding multiple perspectives and looks at each subsurface area, and data from these multiple views can be potentially exploited for improved detection. Despite such potential advantages, sensor development and related processing of forward-looking signals for threat detection presents many new challenges. In this work, we present a novel detection system for forward-looking sub-surface sensor modalities. The system is composed of a prescreener, an anomaly tracking algorithm, and a classifier. For prescreening the performance of a traditional RX detection scheme is compared to a scale-space approach using Laplacian-of-Gaussian (LoG) filtering. The tracking step involves linking prescreener-flagged anomalies that refer to the same subsurface area, taking advantage of the multiple looks provided by the forward looking configuration, which generates a sequence of images for each object encountered by the system. Features are then extracted from these sequences and various statistical models are trained to classify explosive threats from clutter on the data. The proposed algorithm's performance was evaluated on data obtained from a vehicle mounted infrared sensor system with a forward-looking configuration. Our results suggest that incorporating multiple views of the same object in a forward looking system can improve system performance over more naive single-look approaches.

8357-62, Session 15

Inspection of the objects on the sea floor for the presence of explosives

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An ROV constructed for the inspection of objects lying on the coastal sea floor has been described. A variety of objects found on the sea floor needs to be inspected for the presence of materials which represent the threat to the environment and to the human health. In order to establish if an object on the sea floor contains some sort of threat material (explosives, chemical agent), a system using a neutron sensor installed within ROV has been developed. Such a system can inspect the object for the presence of threat materials by using alpha particle tagged neutrons from a sealed tube d+t neutron generator to produce characteristic gamma rays within the interrogated object.

We describe the maritime properties of ROV and show that the measured gamma spectra for commonly found ammunition charged with TNT explosives are dominated by C, O and Fe peaks enabling the determination of the presence of explosives inside an ammunition shell.

8357-63, Session 15

Detection of floating mines in infrared sequences by multiscale geometric filtering

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Automatic detection of floating mines by passive sensing is of major

interest, yet remains a hard problem. In this paper, we propose an algorithm to detect them in infrared sequences, based on their geometry, provided by spatial derivatives.

In infrared images, floating mines contrast with the sea due to the difference of emissivity at low incidence angles: they form bright elliptical areas.

Using the available data and the geometry of our camera, we first determine the scales of interest, which represent the possible size of mines in number of pixels.

Then, we use a morphological filter to enhance the contrast at the selected scales, and calculate for every pixel the Hessian matrix, composed of the second order derivatives, which are estimated in the classical scale-space framework, by convolving the image with derivatives of Gaussian.

Based on the eigenvalues of the Hessian matrix, representing the curvatures along the principal directions of the image, we define two parameters describing the eccentricity of an elliptical area and the contrast with sea, and propose a measure of “mine-likeliness” that will be high for bright elliptical regions with selected eccentricy.

At the end, we only retain pixels with high mine-likeliness, stable in time, as potential mines.

Using a dataset of 10 sequences with ground truth, we evaluated the performance and stability of our algorithm, and obtained a precision between 80% and 100%, and a frame-level recall between 30% and 100%, depending on the difficulty of the scenarios.

8357-64, Session 15

Correction of underwater pincushion distortion by compensating camera lens

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When using flat windows from an air medium to one with higher index of refraction, the surface becomes optically active and a number of aberrations are induced. One affecting the optical control of a remotely-piloted underwater vehicle is the apparent pincushion distortion resulting from Snell’s law at the interface. Small wide-angle lenses typically have the opposite problem, a barrel distortion caused by limitations in the number of lens surfaces and the constraints of cost. An experimental calibration is described in which the barrel distortion of the lens compensated for most of the inherent pincushion of the change in medium. ZEMAX(TM) models will be used to elucidate this phenomenon with a published lens design. With careful selection of the lens, the resultant image can be made almost rectilinear (thus easing steering control).

8357-65, Session 15

Mine countermeasures theory modernization: an integrated approach for automated adaptive mine hunting

G. Garcia, Naval Surface Warfare Ctr. Panama City Div. (United States)

This paper presents a discussion of Mine Countermeasures (MCM) Theory Modernization in light of advances in the areas of autonomy, tactics, and sensor processing. The unifying theme spanning these research areas concerns the capability for in situ adaptation of processing algorithms, plans, and vehicle behaviors enabled through run-time situation assessment and performance estimation. Independently, each of these technology developments impact the Mine Warfare (MIW) Measures of Effectiveness [MOE(s)] of time and risk by improving one or more associated Measures of Performance [MOP(s)]; the contribution of this paper is to outline an integrated strategy for realizing the cumulative benefits of these technology enablers to the Navy’s mine hunting capability. An introduction to the MCM problem is provided to frame the importance of the foundational research and the ramifications of the proposed strategy on the MIW community. We then include an overview of current and future adaptive capability research in the aforementioned areas, highlighting a departure from the existing rigid assumption-based approaches while identifying anticipated technology acceptance issues. Consequently, the paper describes an incremental strategy for transitioning from current mine hunting paradigm where tactical decision aides rely on a priori intelligence and there is little to no in situ adaptation or feedback to a future vision where unmanned systems, equipped with a representation of the commander’s intent, are afforded the authority to adapt to environmental perturbations with minimal human-in-the-loop supervision. The discussion concludes with an articulation of the science and technology issues which the MCM research community must continue to address.

8357-66, Session 15

Preconcentration for the detection of explosives in water

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A sensor system has been constructed that is capable of detecting and discriminating between various explosives in water at the 10-100 parts per trillion level. The sensor discriminates between different compounds using a biologically inspired fluorescent polymer sensor array, which responds with a unique fluorescence quenching pattern during exposure to various explosives. The sensor array was made from commercially available fluorescent polymers coated onto glass beads, and was demonstrated to discriminate between different electron-withdrawing analytes in aqueous solution, including the explosives 2,4,6-trinitrotoluene (TNT) and tetryl, the explosive hydrolysis products 2-amino-4,6-dinitrotoluene and 4-amino-2,6-dinitrotoluene, as well as other explosive-related compounds and explosive simulants. Sensitivities of 10-100 parts per trillion were achieved by employing a preconcentrator (PC) upstream of the sensor inlet. The PC consists of the porous polymer Tenax, which captures explosives from contaminated water as it passes through the PC. As the concentration of explosives in water decreased, longer loading times over the PC were required to concentrate a detectable level of explosive onto the PC, which was released to the sensor array by heating the PC to 190°C. This approach yielded preconcentration factors of up to 100x, which required the PC to sample for proportionally longer time periods. Thus while high levels of preconcentration are achievable, they come at the cost of sampling time. Strategies for decreasing this sampling time are discussed.

8357-67, Session 16

Integration of lidar with the NIITEK GPR for improved performance on rough terrain

C. R. Ratto, K. D. Morton, Jr., Duke Univ. (United States); I. T. McMichael, B. P. Burns, W. W. Clark, U.S. Army Night Vision & Electronic Sensors Directorate (United States); L. M. Collins, P. A. Torrione, Duke Univ. (United States)

Vehicle-mounted ground-penetrating radar (GPR) has proved to be a valuable technology for buried threat detection, especially in the area of military route clearance. However, performance may be degraded very rough terrain or off-road conditions. This is because the majority of signal preprocessing approaches in GPR first identify the ground reflection in the data, and then align the data in order to remove the ground reflection. Under extremely rough terrain, antenna bounce and multipath effects render finding the ground reflection a difficult task, and errors in ground localization can lead to data alignment that distorts potential target signatures and/or creates false alarms. In this work, commercial-off-the-shelf light detection and ranging (LIDAR), global positioning system

(GPS), and inertial measurement unit (IMU) were integrated with a GPR into a prototype route clearance vehicle. The LIDAR provided high-resolution measurements of the ground surface profile, and the GPS/IMU recorded the vehicle's position and orientation. Experiments investigated the applicability of the integrated system for finding the ground reflection in GPR data and decoupling vehicle motion from the rough surface response. Assessment of ground-tracking performance was based on an experiment involving three prepared test lanes, each with different configurations of buried targets and terrain obstacles. Several algorithms for target detection in GPR were applied to the data, both with traditional preprocessing and incorporating the LIDAR and IMU. Experimental results suggest that the LIDAR and IMU may be valuable components for ground tracking in next-generation GPR systems.

8357-68, Session 16

Ground tracking using Microsoft Kinect sensor for ground-penetrating radar

R. H. Luke III, M. A. Cumo, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Ground penetrating radar (GPR) systems have been successfully developed and deployed for explosive ordinance detection in real-world environments. The Husky Mounted Detection System (HMDS) is one such system that has been successfully deployed by the Army for operational mission. Currently, the detection algorithms for HMDS assume a flat earth model and incoming data is manipulated so the air ground interface conforms to this requirement. This manipulation of data occasionally results in missed detections and false alarms. Knowing the exact location of the air ground interface could be used to relax the flat earth assumption and alleviate some of the associated detection problems. This paper describes a method of using the Microsoft Kinect sensor to track the ground for use in the explosive ordinance detection algorithms.

8357-69, Session 16

Extracting edge histogram detector features from ground-penetrating radar data without ground alignment

J. J. Wood, J. N. Wilson, J. Bolton, Univ. of Florida (United States); H. Frigui, Univ. of Louisville (United States)

When processing ground penetrating radar (GPR) data for the detection of subsurface objects it is common to align the data based on the location of the air-ground interface in order to eliminate the effects of antenna motion. This practice assumes that the ground is mostly flat and that variations in the measured ground locations are primarily due to antenna motion. In practice this assumption is often false so ground alignment will cause true ground contours to be flattened, potentially distorting signatures from subsurface objects. In this paper we investigate extracting edge histogram detector (EHD) features from GPR data with varying degrees of alignment: unaligned, fully aligned and aligned only in the down-track direction, where the effects of antenna motion are most prevalent. One problem with not performing ground alignment is that features generated from the ground surface or subsurface layers that follow the contour of the ground may cause false alarms. To address this problem we also consider employing background subtraction prior to feature extraction on aligned data, independent of the alignment method used for feature extraction. We compare the detection performance of algorithms using each of these feature extraction approaches.

8357-70, Session 16

Efficient multiple layer boundary detection in ground-penetrating radar data using an extended Viterbi algorithm

B. Smock, J. N. Wilson, Univ. of Florida (United States)

In landmine detection using vehicle-mounted ground-penetrating radar (GPR) systems, ground tracking has proven to be an effective pre-processing step. Identifying the ground can aid in the correction of distortions in downtrack radar data, which can result in the reduction of false alarms due to ground anomalies. However, the air-ground interface is not the only interface between different regions detectable by GPR systems. Multiple layers can exist in the ground and these sub-surface layers are of particular importance because they also provide anomalous signatures below the air-ground interface, where target signatures will typically reside. In this paper, an efficient method is proposed for performing multiple ground layer-tracking using GPR. The method is an extension of the dynamic programming-based Viterbi algorithm, finding not only the globally optimal path, which can be considered to be the ground surface, but also locally optimal paths that can be considered to be distinct layers within the ground. In contrast with basic Viterbi, this extended method is uniquely suited to detecting not only multiple layers that span the entire antenna array, but layers that span only a subset of the channels of the array. Furthermore, it is able to accomplish this while retaining the efficient nature of the original Viterbi scheme.

8357-71, Session 16

Image registration

R. A. Mueller, NIITEK, Inc. (United States)

The intent of this research is to align an array of GPR (Ground Penetrating Radar) alarms with historical data taken over similar pathways, separated in time, with soft positioning accuracies. The objective is to estimate overlap, reduce false alarms and reveal new alarms showing up in the new data (change detection).

Data is taken with an HMDS (Husky Mounted Detection System) consisting of four radar panels, totaling 48 active receive channels. GPS (Global Positioning System) coordinates are stamped on the data but are only accurate to within several meters, and therein lies the registration problem.

Two approaches have been taken to align the data sets:

1) Image registration of the ground contours (2D) using correlation methods

2) Alarm registration through a string alignment comparison of alarms (2D), using a minimum divergence method.

Radar data are displayed and analyzed within the context of the above algorithms. Data displays are shown in 2D formats: cross track vs depth and down track vs depth.

Preliminary results indicate a positive benefit from these registration processes, including:

- Rapid detection of new alarms
- Reduction of the overall FAR (False Alarm Rate)

This process has possible application to the support of radar systems in operational scenarios by decreasing the load on operators and producing a more rapid ROA (Rate of Advance).

8357-72, Session 17

Keypoint-based image processing for landmine detection in GPR data

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The application of image keypoints to focus image processing has been widely used in image object matching and recognition. Keypoint matching techniques currently provide the best solution for matching and instance recognition of complex objects within cluttered images. The objective in this research is to apply these methods to two-dimensional slices of Ground Penetrating Radar (GPR) data in order to distinguish between landmine and non-landmine responses. Matching algorithms operate by first finding points of interest on similar parts of the same object across different images. A small area, or patch, around each keypoint can be represented by a numerical descriptor that describes the structure of the patch. By matching descriptors from keypoints found in 2-D data to keypoints of known origin to the algorithm can determine the likelihood that any particular patch matches a pre-existing template. In this research, a number of established object matching algorithms are used to distinguish between landmine and non-landmine responses. In addition, landmine specific keypoint and descriptor methods are developed to better suit the landmine detection task within GPR data. These methods improve on the performance of standard image processing techniques that can be applied to GPR data, and show promise for future work involving translations of technologies from the computer vision field to landmine remediation in GPR data.

8357-73, Session 17

Weighted principal component analysis for real-time background removal in GPR data

Y. Shkolnikov, Exponent, Inc. (United States)

Unprocessed ground penetrating radar (GPR) imagery often suffers from horizontal background striations owing to system internal ringing, electronics noise, and/or ground striations. These striations adversely affect the ability to identify buried objects, either via visual inspection of the imagery or by automatic target detection. Singular value decomposition (SVD) is one of the most common techniques for removing these background striations. However the SVD technique suffers from multiple limitations when adapted to real-time analysis of GPR data. First of all, SVD is very computationally intensive especially when processing a 3D image stack. Secondly, SVD is easily contaminated by large values in the image such as those caused by strong reflections from metal objects. Lastly, removal of the first component of SVD may cause removal of both vertical and horizontal striations from the image, whereas in most analyses one is interested in removing only horizontal striations. We propose and demonstrate an alternative technique based on a very fast iterating approximation of the first principal component of the image that suppresses the contamination from strong reflectors. The resulting background removal preserves much more target information and removes a greater percentage of the background compared to the standard SVD-based technique. Moreover, the proposed technique is approximately a factor of 10 faster than SVD making it appropriate for real-time analysis. The new method is demonstrated on both real and synthetic GPR imagery containing simulated buried explosive threats.

8357-74, Session 17

Multiple instance learning for landmine detection using ground penetrating radar

A. Manandhar, K. D. Morton, Jr., L. M. Collins, P. A. Torrione, Duke Univ. (United States)

Ground Penetrating Radar (GPR) has been extensively employed as a technology for detection of subsurface buried threats. Although GPR data is available in 3D space, the object truth (target/false alarm location) is usually only available in 2D space (GPS co-ordinates). In order to mitigate the negative impact of uncertainty in target depth location, several existing algorithms simply extract features from multiple depth regions, which are utilized to perform final mine/non-mine decisions. However, the uncertainty in object depth significantly complicates learning for discriminating targets/non-targets since features at the target location can be significantly different from features at other depths but in the same volume. Multiple Instance Learning (MIL) is a type of supervised learning approach in which labels are available for a collection of feature vectors but not for individual samples (depths). The goal of MIL is to classify new collections of vectors as they become available. This learning method is applicable in the landmine detection problem because features that are extracted independently from several depth bins can be viewed as a set of unlabeled feature vectors, where the entire set either corresponds to a buried threat or a false alarm. In this work, a novel generative Dirichlet Process Gaussian mixture model for MIL is developed that automatically infers the number of mixture components required to model the underlying distributions of mine/non-mine signatures and performs classification using a likelihood ratio test. We show that the performance of the proposed approach for discriminating targets from non-targets in GPR data is promising.

8357-75, Session 17

Incorporation of operator knowledge for improved HMDS GPR classification

L. Kennedy, J. R. McClelland, J. R. Walters, Signal Innovations Group, Inc. (United States)

The Husky Mine Detection System (HMDS) detects and alerts operators to potential threats observed in ground-penetrating RADAR (GPR) data. In the current system architecture, the classifiers have been trained using available data from multiple training sites. Changes in target types, clutter types, and operational conditions may result in statistical differences between the training data and the testing data for the underlying features used by the classifier, potentially resulting in an increased false alarm rate or a lower probability of detection for the system. In the current mode of operation, the automated detection system alerts the human operator when a target-like object is detected. The operator then uses data visualization software, contextual information, and human intuition to decide whether the alarm presented is an actual target or a false alarm. When the statistics of the training data and the testing data are mismatched, the automated detection system can overwhelm the analyst with an excessive number of false alarms. This is evident in the performance of and the data collected from deployed systems. This work demonstrates that analyst feedback can be successfully used to re-train a classifier to account for variable testing data statistics not originally captured in the initial training data.

8357-76, Session 17

A Bayesian method for discriminative context-dependent fusion of GPR-based detection algorithms

C. R. Ratto, K. D. Morton, Jr., L. M. Collins, P. A. Torrione, Duke Univ. (United States)

Ground-penetrating radar (GPR) is a very useful technology for buried threat detection applications which is capable of identifying both metallic and non-metallic objects with moderate false alarm rates. Several pattern classification algorithms have been proposed and evaluated which enable GPR systems to achieve robust performance. However, comparisons of these algorithms have shown that their relative performance varies with respect to the environmental context under which the GPR is operating. Context-dependent fusion has been proposed as a technique for algorithm fusion and has been shown to improve performance by exploiting the differences in algorithm performance under different environmental and operating conditions. Early approaches to context-dependent fusion jointly clustered observations in the joint confidence space of all algorithms and applied fusion rules to each cluster (i.e., discriminative learning). Later approaches exploited physics-based features extracted from the background data to leverage more environmental information, but decoupled context learning from algorithm fusion (i.e., generative

learning). In this work, a Bayesian inference technique which combines the generative and discriminative approaches is proposed for physics-based context-dependent fusion of detection algorithms for GPR. The method uses a Dirichlet process (DP) mixture as a model for context, and relevance vector machines (RVMs) as models for algorithm fusion. Variational Bayes is used as an approximate inference technique for joint learning of the context and fusion models. Experimental results compare the proposed Bayesian discriminative technique to generative techniques developed in past work by investigating the similarities and differences in the contexts learned as well as overall detection performance.

8357-78, Session 17

Uncertainty analysis for a GPR detection algorithm based on the singular value decomposition

M. Walters, E. Garcia, Cornell Univ. (United States)

Ground penetrating radar (GPR) is an effective tool for subsurface detection. It is used in this study to identify landmines and IEDs. This work will investigate the effects of measurement error on the output of an autonomous detection algorithm based on the singular value decomposition (SVD). Removing human operators from the detection process by relying on image processing or other identification algorithms necessitates consideration of errors that are readily rejected by manual interpretation, but not necessarily by automated analysis.

The measured position of automated platforms is subject to uncertainty from imperfect estimates of the platform's location. These uncertainties arise from the limitations of GPS accuracy, wheel encoders, inertial navigation systems, and other sensors. This is particularly important in change detection schemes that compare different scans along the same path to look for newly introduced targets. Sufficient positional fidelity must be achieved for new target signatures to be discernible from computational artifacts generated by measurement error.

In this work simulated radar returns of mines and IEDs, subject to varying levels of uncertainty, will be analyzed with the SVD. SVD analysis of two dimensional radar data yields metrics, singular values and singular vectors, which will be shown to be robust with respect to noise and error. Signal degradation will be measured by investigating the changes in the singular values and vectors under increasing levels of uncertainty. This work is principally investigating the effects of spatial uncertainty, but will additionally consider factors such as clutter and noise.

8357-79, Session 18

Dynamic scene analysis in ground penetrating radar array data

T. Glenn, B. Smock, P. Gader, J. N. Wilson, Univ. of Florida (United States)

Ground Penetrating Radar Array based target detection systems are being deployed in environments with complicated responses due to rough ground surface and subsurface structures. Such complex environments contribute significant numbers of false alarms. In this paper we present a method for dynamic scene analysis using hierarchical particle filters over dynamic Bayesian networks. We evaluate the effectiveness of this method to reduce false alarms caused by environmental effects.

8357-80, Session 18

Classification by using Prony's method with a polynomial model

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Prony's Method with a Polynomial Model (PMPM) is a novel way of doing classification. Given a number of training samples with features and labels, it assumes a Gaussian mixture model for each feature, and uses Prony's method to determine a method of moments solution for the means and priors of the Gaussian distributions in the Gaussian mixture model. The features are then sorted in descending order by their relative performance. Based on the Gaussian mixture model of the first feature, training samples are partitioned into clusters by determining which Gaussian distribution each training sample is most likely from. Then with the training samples in each cluster, a new Gaussian mixture model is built for the next most powerful feature. This process repeats until Gaussian mixture models are built for each feature, and a tree is thus grown with the training data partitioned into several final clusters. A "leave" model for each final cluster is the weighted least squares solution (regression) for approximating a polynomial function of the features to the truth labels. Testing consists of determining a belonging to each cluster, and then regressions are weighted by their belongings and averaged to produce the test confidence.

Evaluation of PMPM is done by extracting features from data collected by both Ground Penetrating Radar and Metal detector of a robot-mounted land-mine detection system, training PMPM models, and testing in a cross-validation fashion.

8357-81, Session 18

Quick Scan (QSCAN): method for real-time anomaly detection using GPR imaging

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Anomaly detection algorithms for ground penetrating radar technologies are often affected by sub-surface soil layers. Sub-surface soil layers are very similar to the soil surface (layer) in that when they exist they are highly variable but typically continuous. Without aligning layers the variability results in both increased false alarms and reduced probability of detection. Given that soil layers are seldom correlated with the surface layer, alignment with the surface typically results in large residuals when using a Least Mean Squares (LMS) approach. Quick Scan (QSCAN) is a novel anomaly detection algorithm that attempts to characterize and remove continuous artifacts due to sub-surface layers and system self-signature. The algorithm performs background estimation by performing a local layer alignment, estimating the similarity of the current scan to the background, and updates the background dynamically by using a sliding weighting scheme. The background is then removed from the original image to highlight only the local anomalies. The algorithm has no latency which allows for the background normalization to be performed in real-time without any look-ahead. QSCAN has been adapted to robotic array sensor prototypes as well as a swept point sensor.

8357-82, Session 18

Evaluation of various feature extraction methods for landmine detection using hidden Markov models

A. Hamdi, H. Frigui, Univ. of Louisville (United States)

Hidden Markov Models (HMM) have proved to be effective for detecting buried land mines using data collected by a moving-vehicle-mounted ground penetrating radar (GPR). The general framework for a HMM-based landmine detector consists of building a HMM model for mine signatures and a HMM model for clutter signatures. A test alarm is assigned a confidence proportional to the probability of that alarm being generated by the mine model and inversely proportional to its probability in the clutter model. The HMM models are built based on features extracted from GPR training signatures. These features are expected to capture the salient properties of the 3-dimensional alarms in a compact representation.

The baseline HMM framework for landmine detection is based on gradient features. It models the time varying behavior of GPR signals, encoded using direction information, to compute the likelihood that a sequence of measurements is consistent with a buried landmine. In particular, the HMM mine models learns the hyperbolic shape associated with the signature of a buried mine by three states that correspond to the succession of an increasing edge, a flat edge, and decreasing edge.

Recently, for the same application, other features have been used with different classifiers. In particular, the Edge Histogram Descriptor (EHD) has been used within a K-nearest neighbor classifier. Another descriptor is based on Gabor features and have been used within a discrete HMM classifier. A third feature, that is closely related to the EHD, is the Bar histogram feature. This feature has been used within a Neural Networks classifier for handwritten word recognition.

In this paper, we propose an evaluation of the HMM based landmine detection framework with several feature extraction techniques. In particular we adapt and evaluate the EHD, Gabor, Bar, and baseline gradient feature extraction methods. We compare the performance of these features using a large and diverse GPR data collection. We identify the strengths and weaknesses of each feature with respect to different categories of alarms. We also propose an approach to fuse these features and use them within a single HMM to take advantages of their strengths.

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8358-01, Session 1

The future of biosurveillance-biosensing strategies

F. R. Jones, Office of Science and Technology Policy (United States)

No abstract available

8358-02, Session 1

Spectrally resolved fluorescence cross sections of aerosolized live biological agents and simulants

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Development and testing of optically-based reagentless sensors for bio-threat agents could be improved if the optical properties of live agents and simulants were better understood. Measurements of the optical properties of agents and simulants prepared and dispersed using different methods could help increase this understanding. We have developed a single particle fluorescence spectrometer system, and have recently setup this system in the biological safety level 3 (BSL3) facility at Edgewood Chemical and Biological Center (ECBC). This setup provides a way to measure spectrally dispersed fluorescence properties of single micron-sized particles containing live agents or simulants. Fluorescence cross sections (from single particles and those averaged over many particles) were measured. The fluorescence emission from individual particles was collected using a large-numerical-aperture Schwarzschild reflecting objective centered at 90 degrees from the direction of the interrogating UV laser beam. The fluorescence cross sections measured were the spectrally resolved differential fluorescence cross sections integrated over this lens. The 3rd and 2nd harmonic generations from a Q-switched, ns-pulsed, narrow band Ti:Sapphire laser (Photonics Industries) that can fire on demand was used for the Ultra-Violet (UV) laser source, so that individual particles, detected in the inlet sample air stream, can be interrogated when they are at the focal volume of the collection optics. Individual particle sizes were estimated using the near-forward elastic scattering from a 705-nm diode laser. Five wavelengths (266, 273, 280, 365, and 405 nm) were used for fluorescence excitation. A UV fluorescence aerodynamic particle size-spectrometer (UV-APS) was used to provide an independent measure of particle size distribution and total fluorescence excited by a 355-nm laser. Aerosol generation and design constraints relating to containment and other safety issues will be discussed. Results for different bacteria and viruses and different preparation methods will be shown.

8358-03, Session 1

Ambient background particulate composition, outdoor natural background: interferents/clutter

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It has proven a very difficult task to discriminate an actual BW threat from the natural occurring ambient particulate aerosol, which includes a significant fraction of particles consisting of mixed mineral and biological material. These interferent particles [clutter](bio and non bio) concentration varies widely both by location, weather and season and diurnally and are composed of fungal and bacterial spores both fragments and components, plant fragments and debris, animal fragments and debris, all of which may be associated with inert dust or combustion material. Some or all of which could also be considered to be an interferent to a biological warfare detector and cause these biodector systems to cause False Alarms in non specific bio detectors. Aerosol components that are interferents for some sensors may not be for others. The composition and concentration of the background environmental aerosol varies significantly by season ,location and time of day, and can be affected by regional and local sources. Regional sources and most local emissions sources generally become dispersed and mixed sufficiently that concentrations remain within a factor of two of the mean. The composition generally changes with time constants of at least several hours. On the other hand, rapid changes in the background aerosol occur when local sources are relatively close to the sample point and outdoor climatic conditions are such that little mixing occurs.I will share analysis of current long term background data sets.

8358-04, Session 1

Proposal for a standoff bioagent detection SWIR/MWIR DISC lidar

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A SWIR/MWIR spectroscopic lidar is proposed for standoff bioagent cloud detection using simultaneous broadband differential scattering (DISC). Measurements and/or modeling of DISC spectra of simulants are revisited and the rational of the SWIR/MWIR DISC approach is explained, especially in light of the LWIR DISC experiments and conclusions done elsewhere. Preliminary results on the construction of a low power non-linear broadband source in the SWIR/MWIR are presented. Light from a 1064nm pump laser is passed through a period and temperature tunable PPMgO:LN OPG to generate broadband light with a full width at half maximum (FWHM) of 10 to >100nm in the SWIR/MWIR between 1.5 and 3.9µm. Broadband coherent light from this source is to be emitted towards a cloud that generates back-scattering. This source is being used in a short range chemical remote detection breadboard, showing the possible dual use of the set-up. Light collected by the receiver telescope is coupled to a grating spectrometer and the return signal (DISC in the proposed setup) is detected using a gated MCT-APD array in much the same way clouds are interrogated using UV-LIF. A programmable volume of space along the laser beam path is imaged at the entrance of the spectrometer and 320 spectral channels can be measured simultaneously, attenuating the effects of atmospheric instabilities on DISC measurements. Proposed follow on work will be presented.

8358-05, Session 1

Automated recognition and tracking of aerosol threat plumes with an IR camera pod

R. A. Fauth, T. C. Gruber, Jr., C. Powell, MESH, Inc. (United States); D. Clapp, Ipswich Engineering Group (United States)

Protection of fixed sites from chemical, biological, or radiological aerosol plume attacks depends on early warning so that there is time to take mitigating actions. Early warning requires continuous, autonomous, and rapid coverage of large surrounding areas; however, this must be done at an affordable cost. Once a potential threat plume is detected though, a different type of sensor (e.g., a more expensive, slower sensor) may be cued for identification purposes, but the problem is to quickly identify all of the potential threats around the fixed site of interest. To address this problem of low cost, persistent, wide area surveillance, an IR camera pod and multi-image stitching and processing algorithms have been developed for automatic recognition and tracking of aerosol plumes. A rugged, modular, static pod design, which accommodates as many as four micro-bolometer IR cameras for 45deg to 180deg of azimuth coverage, is presented. Various Open CV based image processing algorithms, including stitching of multiple adjacent FOVs, recognition of aerosol plume objects, and the tracking of aerosol plumes, are presented using process block diagrams and sample field test results, including chemical and biological simulant plumes. Methods for dealing with the background removal, brightness equalization between images, and focus quality for optimal plume tracking are also discussed.

8358-06, Session 1

XPairIt: novel software toolkit design for smart reagent development

M. S. Sellers, M. M. Hurley, U.S. Army Research Lab. (United States)

The development of smart peptide binders requires an understanding of the fundamental mechanisms of recognition which has remained an elusive grail of the research community for decades. Recent advances in automated discovery and synthetic library science show great promise for the development of recognition elements with improved stability, affinity and specificity. In addition, these advances provide a wealth of information to probe these fundamental details and develop improved models for a priori prediction of affinity and specificity. Here we present the modeling portion of an iterative experimental/computational study to produce high affinity peptide binders to the Protective Antigen (PA) of Bacillus anthracis. The result is a general usage, HPC-oriented, python-based toolkit based upon powerful third-party freeware, which is designed to provide a better understanding of peptide-protein interactions and ultimately predict and measure new smart peptide binder candidates.

We present an improved simulation protocol with flexible peptide and protein docking, coarse grain and atomistic models, on-the-fly molecular dynamics, and explicit water representation. Candidate peptides are docked with the Anthrax Protective Antigen and Lethal Factor, and binding locations and affinities are reported.

8358-07, Session 2

Multiplex pathogen and toxin assays using a microflow cytometer

P. B. Howell, Jr., U.S. Naval Research Lab. (United States)

A microflow cytometer has been developed that utilizes microfluidic technology to produce robust, 3-dimensional sheath flow. The system uses fluorescence-coded microspheres that are focused using passive groove structures for laser interrogation for identification and quantitation of target species. Optical interrogation is performed via embedded optical fibers for both the illumination and collection of emitted and scattered light. Analysis at four different wavelengths is used to identify 13 sets of coded microspheres and can quantify target bound by the presence of phycoerythrin-labelled tracer. The microcytometer can detect targets such as Escherichia coli, Listeria, Salmonella, cholera toxin, staphylococcal enterotoxin B (SEB), and ricin. The microsphere mixture was used to perform multiplexed sandwich immunoassays on samples spiked with bacteria or toxin, generating dose-response curves. The microflow cytometer, with the aid of an amplification protocol, established limits of detection: E. coli, 10e3 cfu/mL; Listeria, 10e5 cfu/mL; Salmonella, 10e5 cfu/mL; cholera toxin, 1.6 ng/mL; SEB, 0.064 ng/mL; and ricin, 8.0 ng/mL. Detection of small molecules, including toxins and explosives have also been demonstrated via displacement assays.

8358-08, Session 2

Novel utilization of the outer membrane proteins for the identification and differentiation of pathogenic versus nonpathogenic microbial strains using mass spectrometry-based proteomics approach

R. E. Jabbour, U.S. Army Edgewood Chemical Biological Ctr. (United States)

Mass spectrometry based proteomic approaches are showing promising capabilities in addressing various biological and biochemical issues. Outer membrane proteins (OMPs) are often associated with virulence in gram-negative pathogens and could prove to be excellent model biomarkers for strain level differentiation among bacteria. Whole cells and OMP extracts were isolated from pathogenic and non-pathogenic strains of Francisella tularensis, Burkholderia thailandensis, and Burkholderia mallei. OMP extracts were compared for their ability to differentiate and delineate the correct database organism to an experimental sample and for the degree of dissimilarity to the nearest-neighbor database strains. This study addresses the comparative experimental proteome analyses of OMPs vs. whole cell lysates on the strain-level discrimination among gram negative pathogenic and non-pathogenic strains.

A comparison of the proteins present in whole cell and OMP extracts of Burkholderia Thailandensis vs. Burkholderia mallei showed relatively equal number of species-unique proteins, i.e. 148 vs. 146 respectively. Near-neighbor analyses, using Ward's hierarchical clustering method, of the OMPs data indicated an ambiguous strain level identification from database matching for the experimental samples and the database Burkholderia thailandensis strain E 264 and Burkholderia mallei entries. The former strain was matched only to the non-pathogenic strain (E 264), while the pathogenic one had equal match to the Burkholderia mallei and pseudomallei pathogenic strains in the database. The set of unique proteins for the whole cell extracts of Burkholderia mallei showed 68 strain-unique peptides of which 13 protein biomarkers were associated with virulence factors.

8358-09, Session 2

Bacterial display peptides for use in biosensing applications

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Recent advances in synthetic library engineering continue to show promise for the rapid production of reagent technology in response to biological threats. However, a critical need for an improved understanding of the mechanisms of recognition and the tools to enable this understanding remains. This works combines existing experimental

methodology (SPR, ELISA, PCR) with an improved multi-scale (coarse-grained to quantum) High Performance Computing compatible computational framework for the generation, analysis, and prediction of binding affinity and specificity of docked protein-peptide complexes. The computational framework produced will be of general utility for rapid prescreening of candidate ligands for a “smart” binder for future CB threat protein targets. In this paper, we will report on recent advances in rapid and automated discovery and the characterization of reagents produced using this technology. Specific results on peptides binders to Protective Antigen (PA) protein of Bacillus anthracis and Staphylococcal Enterotoxin B (SEB) will be presented. Highlights of on cell vs. off-cell affinity, cross-reactivity performance, and domain mapping will be presented. Correlation of the results with advanced docking simulations on the protein-peptide system for the development of a unique modeling toolkit that would allow researchers to prescreen candidates for binding affinity and provide insight to smart binder development.

8358-10, Session 2

Multi-wavelength, resonance Raman spectroscopy of bacteria to study the effects of growth phase and culture medium

N. Kunapareddy, S. Nikitin, Research Support Instruments, Inc. (United States); J. Grun, D. Gillis, R. Lunsford, Z. Wang, U.S. Naval Research Lab. (United States)

We will examine the use of multi-wavelength UV resonance-Raman signatures to identify the effects of growth phase and culture media on different types of bacteria. Gram positive and gram-negative species, Escherichia coli, Bacillus cereus, Citrobacter koseri and Citrobacter braakii were grown to logarithmic and stationary phases in different culture media. Raman spectra of bacteria were obtained by sequential illumination of samples between 220 and 260 nm; a range which encompasses the resonance frequencies of cellular components. The individual spectra are processed and assembled to form a two-dimensional signature. In addition to the information contained in the single spectrum, this two-dimensional signature contains information reflecting variations in resonance cross sections with illumination wavelength. We will discuss the distinct features of these signatures and present results of our algorithms in identifying the differences between these germs. Preliminary results indicate that both growth phase and culture medium affect the Raman signature, but not to an extent that would negate identification of the species. We have previously demonstrated the successful use of two-dimensional signatures to distinguish between different types of bacteria, chemicals and explosives and also in identifying constituent components in chemical mixtures.

This work is supported by the Defense Threat Reduction Agency Joint Science and Technology Office.

8358-11, Session 3

Remote sensing and testing capabilities at U.S. Army Dugway Proving Ground

J. T. Pearson, U.S. Army Dugway Proving Ground (United States)

U.S. Army Dugway Proving Ground (DPG) is a major defense test range with the mission of testing chemical and biological defense systems and materials. DPG facilities include state-of-the-art laboratories, extensive test grids, controlled environment calibration facilities, and a variety of referee instruments for required test measurements. Among these referee instruments, DPG has built up a significant remote sensing capability for both chemical and biological detection. Technologies employed for remote sensing include FTIR spectroscopy, UV spectroscopy, Raman-shifted eye-safe lidar, and other elastic backscatter lidar systems. These systems provide referee data for bio-simulants, chemical simulants, toxic industrial chemicals (TICs), and toxic industrial materials (TIMs). In order to realize a successful large scale open-air test, each type of system requires calibration and characterization. DPG has developed specific controlled environment calibration facilities to meet this need. These facilities are the Joint Ambient Breeze Tunnel (JABT), and the Active Standoff Chamber (ASC). The JABT and ASC are open ended controlled environment tunnels. Each includes validation instrumentation to characterize a given simulant release within the tunnel. Standoff systems can be positioned at field test distances to collect data from the characterized simulant in order to calibrate sensitivity. Data from different types of systems can be easily correlated using this method, making later test data more meaningful. Once this is accomplished, DPG has a variety of large scale test grids available for field tests. Meteorological data is collected year round on these test grids to help predict the conditions for a desired test date. After and during testing, data from the various referee instruments is provided in a visual format to more easily draw conclusions on the results. This presentation provides an overview of DPG’s standoff testing facilities and capabilities, as well as example data from different test scenarios.

8358-12, Session 3

Biomolecule Raman spectral temporal flux from resting Bacilli spores in deionized water matrix

A. P. Snyder, U.S. Army Edgewood Chemical Biological Ctr. (United States); A. Tripathi, SAIC (United States); R. E. Jabbour, P. G. Wilcox, J. A. Guicheteau, U.S. Army Edgewood Chemical Biological Ctr. (United States)

Raman microspectroscopy is used to probe the age parameter for detection and characterization of Bacillus spores in distilled water (DIW). Live suspensions of Bacillus anthracis Sterne, Bacillus atrophaeus, and Bacillus thuringiensis were prepared. Aliquots at 5 min, 5 hr, and 1, 2, and 7 days were dried on microscope slides. There was discrimination with respect to age. For each class, the time parameter provided separation for the bacterial resting suspensions from a multivariate dendrogram analysis. When all age data were placed together, significant overlap occurred. The one day information caused the overlap. Temporal spectral analysis suggests a pre-germination or molecular information activity (MIA) from the fresh to one day suspensions consisting of energy expenditure to ‘test the waters’ for the presence of growth media. After that period of time and without growth media, the spores reduce the MIA. It appears that a spore is not dormant when resting in DIW. Raman spectroscopy provides clues as to the biomolecules that are created and/or mobilized. The hypothesized MIA may affect database spectral matching procedures from a temporal point of view. Environmental liquids usually do not contain bacterial growth media. The current work shows a one day resting period where MIA is present in a spore. Avoidance of the collection of Raman spectra at this time period may allow better database spectral matching of bacterial spores found in environmental water samples. Raman spectroscopy can be considered as a trigger to mobilize techniques such as proteomic, genomic, or biomolecular identification methods.

8358-13, Session 3

Spectroscopic investigations of surface deposited bacterial BW simulants

M. J. Baker, S. J. Barrington, S. Pelfrey, Defence Science and Technology Lab. (United Kingdom)

The defence against the use of biological weapons (BW) is becoming an increasingly important concern which is reflected in the National Security Strategies of the USA and UK. The UK has highlighted international terrorism affecting the UK or its interests, including a chemical biological, radiological or nuclear attack by terrorists as a tier one risk1. The USA specifically mentions countering the biological threat to strengthen resilience across the spectrum of high-consequence biological threats2.

Many BW agents will remain viable in the environment for a substantial

period of time posing a continued risk, hence there is a requirement to facilitate hazard avoidance, control of the spread of the hazard, exposure management and decontamination confirmation.

This paper will discuss the use of spectroscopy combined with pattern recognition algorithms and its use for detecting surface deposited BW simulants. Spectroscopy is quick, cost-effective, simple to operate, reagent free and requires simple sample preparation. The bacterial strains analysed were selected to cover a range of bacterial groups representative of BW threat agents and common environmental bacteria (Bacillus atrophaeus, Bacillus thuringiensis var kustaki, Bacillus thuringiensis ATCC 29730, Escherichia coli MRE 162, Pantaeoa agglomerans ATCC 33243 and Pseudomonas fluorescens ATCC 13525). This paper will also discuss the impact of environmental conditioning (a daily cycle of temperature and humidity for 30 days) of these simulants on the spectroscopic signatures and pattern recognition models. The temperature and humidity conditions are within the ranges prescribed in the Ministry of Defence Standard on Natural Environments and measurements from Camp Bastion, Afghanistan.

[1] A Strong Britain in an Age of Uncertainty: The National Security Strategy, CM7953, October 2010.

[2] National Security Strategy 2010, United States Government, May 2010.

8358-14, Session 3

Eyesafe fusion detection (ESFD) of CBE threats

M. P. Nelson, P. J. Treado, O. Klueva, R. C. Schweitzer, ChemImage Corp. (United States)

Existing CBE detection technologies often require close proximity for sensing or detecting, endangering operators and costly equipment. While several standoff sensors exist for the detection of CBE, many of these sensors are laser-based presenting an eye safety risk for personnel who enter the nominal ocular hazard zone of the laser beam. Furthermore, most of the existing explosives detection technologies lack the ability to support autonomous, real-time, on-the-move (OTM) architectures.

The Eyesafe Fusion Detection (ESFD) of CBE Threats project is a multi-year sensor development effort, led by ChemImage Corporation in cooperation with the Army Research Laboratory (ARL). The ESFD sensor fully integrates Raman, RGB, SWIR and LWIR sensors providing wide area surveillance, local area surveillance and local area confirmation capabilities for CBE detection. The sensor provides real-time, active strategies for surveillance and safe laser operation of areas being scanned by the high energy lasers. This is accomplished by implementing motion detection and people detection and tracking algorithms to sense and react to personnel approaching the nominal ocular hazard zone of the laser beam.

ESFD technology has the potential to allow the warfighter to operate a laser-based system for the detection of CBE, while maximizing eye safety. Such capability is needed for combat engineers to support route-clearance applications, as well as site reconnaissance and explosive ordnance disposal (EOD) missions - ultimately to save the lives of soldiers and civilians.

In this paper, results from the ESFD sensor will be discussed.

8358-15, Session 3

Detection of single-digit Bacillus anthracis spores in water within 15 minutes by SERS

S. R. Farquharson, Real-Time Analyzers, Inc. (United States)

The US Military is highly dependent on indigenous water supplies to hydrate its deployed forces during all aspects of operations. Such water supplies are considered prime targets to effect a biological attack. Consider that nearly 50% of all troops in Afghanistan and Iraq have suffered from pathogen induced diarrhea, often from drinking water. Despite the substantial effort to develop bioagent analyzers since the 2001 distribution of anthrax through the US Postal System, current analyzers are either to slow (e.g. PCR, 1 measurement/hour), have high false-alarm rates (e.g. immunoassays), lack sensitivity (e.g. Raman), are not field-usable (e.g. GC-MS), and often, cannot be multiplexed to identify multiple species (e.g. PCR). Consequently, there is a critical need for a field-usable analyzer that can detect a broad range of bioagents and waterborne pathogens at exceptionally low concentrations (e.g. 1000 B. anthracis spores per liter water), and at relatively fast speed (minutes) to ensure such water supplies are safe for drinking. To meet this need we have been developing a sample system that selectively binds specific bioagents and produces surface-enhanced Raman spectra (SERS). Here we present discriminate detection of single-digit B. anthracis spores in 15 minutes.

8358-16, Session 4

Empirical methods for identifying specific peptide-protein interactions for smart reagent development

J. M. Kogot, D. A. Sarkes, U.S. Army Research Lab. (United States); C. R. Warner, T. J. Henderson, J. P. Carney, U.S. Army Edgewood Chemical Biological Ctr. (United States); D. N. Stratis-Cullum, U.S. Army Research Lab. (United States)

The current state of the art in the development of antibody alternatives is fraught with difficulties including mass production, robustness, and overall cost of production. The isolation of synthetic alternatives using peptide libraries offers great potential for recognition elements that are more stable and have improved binding affinity and target specificity. Although recent advances in rapid and automated discovery and synthetic library engineering continue to show promise for this emerging science, there remains a critical need for an improved fundamental understanding of the mechanisms of recognition. An iterative experimental and computational approach could be used to develop a toolkit capable of prescreening candidates for binding affinity and provide insight to smart binder development. Using a 15 amino acid peptide sequences isolated from bacterial display libraries, high affinity and specificity peptides to protective antigen (PA) protein of Bacillus anthracis have been identified. Additionally, an epitope mapping strategy using single domain constructs of PA has been created to determine the exact protein interaction site of the peptides. Experimental methods such as capillary electrophoresis, flow cytometry, circular dichroism, and NMR in concert with modeling results are necessary to support computational modeling predictions. Determining binding locations, protein and peptide residues critical for binding, and the structural requirements for binding are all critical for improving reagent development. The experimental data derived from the epitope mapping provides an isolated region for modeling simulations to predict and confirm binding and subsequently predict mutations in the peptide molecular recognition element that could enhance peptide binding to the target.

8358-17, Session 4

The use of handheld Raman system for virus detection

C. Song, The Univ. of Georgia (United States); J. D. Driskell, Illinois State Univ. (United States); R. A. Tripp, Y. Zhao, The Univ. of Georgia (United States)

The combination of surface enhanced Raman scattering (SERS) with a handheld Raman system would lead a powerful portable device for defense and security applications. The Thermo Scientific FirstDefender RM instrument is a 785-nm handheld Raman spectrometer intended for rapid field identification of unknown solid and liquid samples. Its availability and effectiveness of SERS-based detection have been confirmed first by a sensitive SERS measurement with BPE as a reporter on a silver nanorod (AgNR) substrate engineered by the UGA team,

and compared to the results obtained by a commercial confocal Bruker Raman system. This portable handheld Raman spectrometer is used, for the first time, to detect and identify three types of influenza viruses, namely Texas (TX), Pennsylvania (PA), and Mute Swan (MS), and their negative control, i.e. Allantoic fluid (AF), with a multiwell AgNR SERS chip. The obtained SERS spectra with rich peaks demonstrate that the instrument can be used for SERS-based influenza virus detection. According to the SERS spectra, these different influenza viruses can be further distinguished successfully from the negative control via the principal component analysis (PCA) and partial least squares-discriminate analysis (PLS-DA). Our results demonstrate that the combination of good and reproducible SERS substrates with portable Raman device can generate a powerful field device for chemical and biological sensing.

8358-18, Session 4

Testing and comparison of the coating materials for immunosensors on QCM

H. Nazir, Ankara Üniv. (Turkey); A. Öztuna, Gulhane Military Medical Academy (Turkey)

In immunoassay based biosensor development studies polymers, as a matrix, and thiol, amine and aldehyde derivative compounds, as a antibody linker, are to be experimented. Aim of this study is to test amine and acetate functional group containing derivatives in liquid phase in order to develop an antibody immobilization strategy for quartz crystal microbalance (QCM) system. In our study, 4-aminothiophenol (4-AT), carboxylated-PVC (PVC-COOH) and aminated-PVC (PVC-NH2) compared with each other as a coating material. Surface of the coated AT-cut gold crystals were characterized with Fourier Transform Infrared spectrometry (FTIR) and Scanning Electron Microscope (SEM) and tested in a Bacillus anthracis (GenBank:GQ375871) immunoassay model system. Subsequently, a series of SEM micrographs were taken again in order to investigate surface morphology and show the presence of the B. anthracis spores on the sensor surface. Results showed that 4-AT coated QCM-sensor had the lowest detection limit. Furthermore, it concluded that, B. anthracis spores can be accomplished by using -NH2 functional group containing derivatives on QCM without requiring complicated immobilization procedures and expensive preliminary preparations.

8358-68, Poster Session

New methods and an optical device for active remote sensing of chemical and biological agents

V. A. Yatsenko III, Institute of Space Research (Ukraine)

This report focuses on a new methodology and an experimental optical device for detection and identification of biological and chemical agents including various toxins and viruses. The proposed approach is based on pattern recognition optimization techniques and new indexes [1-4]. The ecological interest is in response to a proliferation of agents development and threats for human health. Additionally, there is a pervasive interest across diverse application areas such as medicine, environmental protection, and vegetation processing to achieve a rapid detection and identification capability of various agents. In many cases, a standoff capability is desired. Technologies such as optical spectroscopy measurements, laser induced fluorescence, pattern recognition and optimization methods will be used in our device [1,2]. This device is intended to be used for ground measurements or can be installed on small airplanes for remote sensing.

In this report we concentrates on environmental dynamic probabilistic risk assessment with complex characterizations for hazards using physical models a predictable level of biological and chemical agents [3,4]. Focusing is given mainly on vegetation models, mathematical models for dynamic probabilistic risk assessment and software for the modeling and prediction of an ecological systems state. The probabilistic risk assessment method is presented to evaluate some deterministic and stochastic factors. Probabilistic risk assessment is a comprehensive, structured, and logical analysis method aimed at identifying and assessing risks in ecological systems in order to cost-effectively improve their safety and performance. This method is based on the Conditional Value-at-Risk (CVaR) and on the expected loss exceeding Value-at-Risk (VaR).

We propose a new dynamical information approach for risk assessment of ecological systems affected by biological and chemical agents. Our approach includes the following steps: dynamical modeling of environmental systems, modeling of biological and chemical agents influences on ecological systems, probabilistic risk assessment, and risk minimization. Black-box models of biological and chemical agents influences on ecological systems are developed for risk assessment.

A new methods and algorithms will be presented, which are feasible for cooperative execution of complex tasks by multiple autonomous unmanned vehicles (both aerial (UAV) and ground (UGV)) during intricate missions. The UAV is equipped with special remote sensing equipments, including a laser fluorosensor for oil spill detection. The UAV provide a platform for developing new sensors and techniques for detecting oil and chemical agents.

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8358-69, Poster Session

Optical properties of diffuse thin films that also fluoresce

R. I. Joseph, M. E. Thomas, D. M. Brown, E. P. Thrush, The Johns Hopkins Univ. Applied Physics Lab. (United States)

The Kubelka- Munk model is applied to represent the transmittance and reflectance of diffuse thin films of biological spores. From this representation the absorption and scatter properties of the film can be obtained in the ultraviolet and visible regions. Furthermore, the original Kubelka- Munk theory has been extended by numerous authors for application to fluorescent media. In the case of polychromatic incident light only approximate solutions to the resulting integro-differential equation have been found. An exact solution is presented. In the case of monochromatic incident light the theory simplifies and the general solution is presented. Experimentally, the reflectance and transmittance are obtained for a film of finite thickness backed by a reflective substrate. Additionally, by illuminating the thin film using 355 nm laser radiation, spectrally resolved fluorescence is obtained for the same film. The experimental findings are then compared to the modeled result.

8358-70, Poster Session

I-SCAD® overview

M. Popa, Chemring Detection Systems, Inc. (United States)

This paper presents the capabilities and system-level description of the I-SCAD® standoff chemical agent detector. The I-SCAD® is the commercial variant of the Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD). It is a standoff, passive, Fourier Transform

Infrared (FTIR)-based remote sensing system for detecting chemicals of interest including warfare agents and toxic industrial ones, while discriminating against battle-space interferents. The I-SCAD® has two Field Of View (FOV) configurations, 1.5 degrees (27 millradians) and 0.5 degrees (9 millradians), furnishing 360-degree coverage for a detection range up to 6 km. This capability allows personnel to avoid contaminated areas or don protective gear. The system can accommodate various platforms such as those for fixed sites and ground mobile scenarios for on-the-move reconnaissance and surveillance. The core of the system is a rugged Michelson interferometer operating in the 7-14 micron region of the infrared spectrum. Command, control, and processing electronics have been upgraded with state-of-the-art microprocessors to take advantage of advances in microelectronics with significantly improved throughput capability and reduced power dissipation. The operator interface solution consists of a commercial, off-the-shelf computer with a custom docking station.

8358-73, Poster Session

Micro-optics for simultaneous multispectral imaging applied to chemical/biological and IED detection

M. Hinnrichs, Pacific Advanced Technology, Inc. (United States)

Using diffractive optical micro-lenses configured in an array and placed in close proximity to the focal plane array will enable a small compact simultaneous multispectral imaging camera. This approach can be applied to spectral regions from the ultraviolet (UV) to the long-wave infrared (LWIR). The number of simultaneously imaged spectral bands is determined by the number of individually configured diffractive optical micro-lenses (lenslet) in the array. Each lenslet images at a different wavelength which is predetermined based on application at the time of manufacturing. In addition, modulation of the focal length of the lenslet array with piezoelectric actuation will enable spectral band fill-in allowing hyperspectral imaging. Using the lenslet array with dual-band detectors will increase the number of simultaneous spectral images by a factor of two when utilizing multiple diffraction orders.

Configurations and concept designs will be presented for detection application that are applied to biological/chemical agent, buried IED's and weapons labs. These design concepts will be backed up with data collected using the Warlock hyperspectral infrared camera at Dugway Proving Ground and Nevada Test Site in recent years sponsored by ECBC and JIEDDO.

The simultaneous detection of multiple spectral images in a single frame of data enhances the image processing capability by eliminating temporal differences between colors and enabling a handheld instrument that is insensitive to motion.

8358-74, Poster Session

The effect of morphology on the detection of explosive traces by ultraviolet spectroscopic differential reflectometry

T. A. Dubroca, G. Guetard, R. E. Hummel, Univ. of Florida (United States)

Among the various techniques for detecting explosives, differential reflectometry is distinguished by its speed of screening (about one second), safety (no x-rays or laser beams), and the fact that it is fully automatic, that is, it does not require an operator and human judgment. Moreover, the technique does not compromise privacy. Briefly, white light (200-500 nm) is shone on a surface to be investigated, such as a piece of luggage at an airport or a parcel at a mail-sorting facility. Upon reflection, the light is collected with a spectrometer combined with a CCD camera. A computer processes the data and produces in turn a differential reflection spectrum taken between two adjacent areas of the surface. This differential technique is highly sensitive and provides spectroscopic data of explosives. As an example, 2,4,6, trinitrotoluene (TNT) displays strong and distinct features in differential reflectograms near 420 nm. Similar, but distinctly different features are observed for other explosives.

One of the most important criteria of explosives screening is the limit of detection. We present here, how the limit of detection is affected by various environmental conditions, such as the sample surface morphology (roughness, particle size, particle distribution, angle of incidence, etc). We show that the peak intensity ranges within several orders of magnitude, specifically, from nano-grams to micro-grams depending on the sample morphology.

8358-75, Poster Session

Isolation and characterization of anti-SEB peptides using magnetic sorting

J. M. Pennington, J. M. Kogot, D. A. Sarkes, D. N. Stratis-Cullum, U.S. Army Research Lab. (United States)

Peptide display libraries offer an alternative method to existing antibody development technologies for rapidly isolating highly stable reagents for detection of new and emerging biological threats. Bacterial display libraries are used to isolate new peptide reagents within 1 week rather than 3 months for antibody development, and it is also timelier than using phage or yeast display libraries. Using magnetic sorting methods, we have isolated peptide reagents with high affinity and specificity to staphylococcal enterotoxin B (SEB), a suspected food pathogen. Using flow cytometry methods for on-cell characterization and standard immunoassays for the peptide reagent characterization, we have determined the binding affinity of this new peptide reagent. In addition, daughter libraries are generated by randomizing the original, isolated peptide sequence to potentially find additional reagents with increased affinity or specificity compared to the original sequence. Magnetic sorting for new reagents using bacterial display libraries is a rapid and effective method for isolating detection molecules for current and new and emerging food pathogen targets.

8358-19, Session 5

Deep-UV Raman measurements of energetic materials and their photochemical products

S. A. Asher, Univ. of Pittsburgh (United States); D. D. Tuschel, HORIBA Jobin Yvon Inc. (United States); L. Wang, M. K. Ghosh, T. A. Vargson, Univ. of Pittsburgh (United States)

We have measured deep UV resonance Raman spectra of explosive molecules with the objective of determining the optimal stand-off methods to identify and quantitate them in environmentally complex samples. We will discuss Raman cross sections of both solution and solid samples and the role of photochemistry in modifying their spectral signatures.

8358-20, Session 5

Challenges of infrared reflective spectroscopy of solid-phase explosives and chemicals on surfaces

M. C. Phillips, B. E. Bernacki, J. D. Suter, T. J. Johnson, Pacific Northwest National Lab. (United States)

Reliable active and passive hyperspectral imaging and detection of explosives and solid-phase chemical residue on surfaces remains a challenge and an active area of research and development in the CRBNE community. Both methods seek to exploit libraries of reference spectra as well as data-extracted endmembers to determine the presence of target materials using various spectroscopic detection algorithms. However, in

some cases neither the reference transmission spectra of thin films nor the integrated reflectance spectra of neat solids provide the reference spectra that adequately resemble the instrumental signals scattered from real-world objects such as curved metallic painted surfaces. Many factors contribute to this phenomenon: the influence of the surface on which the chemical resides, whether the material is crystalline or amorphous, particle size, sample hydration, Reststrahlen effects, speckle, diffraction and interference arising from laser illumination, as well as residue thickness. In many cases it is not possible to collect enough spectra to anticipate the variety of conditions that might be encountered; we therefore describe a physics-based model using the dispersive complex dielectric constant to explain what is often thought of as anomalous behavior of scattered or non-specular signatures encountered in active and passive sensing of explosives or chemicals on surfaces and show modeling and experimental results for RDX.

8358-21, Session 5

High-resolution optical signatures of fresh and aged explosives

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Optical signatures of fresh and aged explosives are measured and compared to determine whether there exist differences in the signatures that can be exploited for detection. The explosives are RDX, TNT, and HMX, which have been heated for two weeks at 75 degrees centigrade or irradiated for two weeks with a 15-Watt ultraviolet lamp (254nm). Signatures of typical binders, aged the same way as the explosives, are also measured - as are the signatures of fresh TNT and its environmental decomposition products.

The optical signatures are obtained by illuminating the samples with a sequence of laser wavelengths between 210nm and 700 nm and measuring the spectra of light scattered from the sample at each laser wavelength. The measurements are performed on the Naval Research Laboratory's SWOrRD instrument. SWOrRD is capable of illuminating a sample with laser wavelength between 210nm and 2000nm, in steps of 0.1nm, and measuring the spectrum of light scattered from the sample at each wavelength. SWOrRD's broad tuning range, high average power (1- 300mW), narrow line width (< 4cm-1), and rapid wavelength tunability enable these measurements.

Results, based on more than 170 measurements - each at about 20 laser wavelengths, indicate that the variation in spectral line amplitude observed when altering laser illumination wavelength differs between fresh and aged explosives. Thus, an instrument for rapid and reagent-less differentiation between aged and fresh explosives, based on illumination with a few appropriately chosen laser wavelengths appears feasible.

This work sponsored by ONR

8358-22, Session 5

Use of a spectroscopic lidar for standoff explosives detection through Raman spectra

F. Babin, R. Forest, D. Gay, N. Ho, O. Pancrati, S. Deblois, INO (Canada); S. Desilets, J. Maheux, Defence Research and Development Canada, Valcartier (Canada)

This paper assesses the potential of detecting explosives (RDX, TNT, PETN, HMX, HMTD, Urea Nitrate) from a distance with a spectroscopic lidar system. For the study, the temporal and spectral resolutions of laser induced fluorescence lidar prototypes were enhanced. The integrated breadboards used easily available Nd:YAG laser wavelengths (266 nm, 355 nm, and 532 nm) to remotely detect the Raman signatures induced in traces of explosives deposited on surfaces. The spectroscopic lidar setup allows for time resolved measurements with high temporal resolution. Raman spectra are observable, even in the presence of fluorescence. Experiments with low average laser power (tens of mWs) have shown the unambiguous capability to detect and identify explosives at distances ranging up to 20 m. Thanks to the combination of UV wavelength for higher Raman cross-sections and efficient gated detection the 355nm prototype yielded the best compromise. Excitation at 266 nm was expected to yield a better Raman response and was investigated. Less than optimal laser parameters, detection efficiency and strong fluorescence reduced the signal to noise ratio of the 266nm signals with respect to those at 355 nm and 532 nm showing the importance of optimizing system parameters for high sensitivity detection. Besides the description of the prototypes and an early assessment of their performances, recommendations are also proposed to improve the instrument, leading to an efficient remote sensor for explosives.

8358-23, Session 5

Recent improvements and testing of a check point explosives detection system

A. Ford, R. D. Waterbury, D. Vunck, T. B. Blank, A. J. Hopkins, B. Ferguson, T. McVay, E. Dottery, Alakai Defense Systems, Inc. (United States)

Improvised explosive devices (IEDs) and homemade explosives (HMEs) are at the forefront of threats faced in both military and civilian environments. Homemade explosives and IEDs come in a number of different forms that are not only difficult to find, but can also be extremely dangerous to detect at close range due to the blast effect of the explosives. Stopping the spread of HMEs and the construction of IEDs from a safe distance (i.e., standoff ranges) is therefore high priority for national security.

Alakai Defense Systems has created a standoff explosive detection sensor called the Check Point Explosives Detection System (CPEDS) for use at military check points. The system is designed to find trace explosive residues from a standoff distance to thwart the transport and use of illegal homemade explosive precursors and other explosive-related contraband. Because of its standoff nature, this instrument could offer benefits to those conducting searches for explosives, since it takes them out of harm's way if a detonation should occur.

Recently, the system underwent a second round of double-blind performance testing at a government facility. The testing was designed to determine several metrics of the device when presented with explosive materials at different concentrations. A short description of the instrument, improvements to the system over the past year, and a brief overview of the testing are presented here.

8358-24, Session 5

Standoff detection results with the infrared hyperspectral MoDDIFS sensor

G. Fortin, AEREX avionique inc. (Canada); J. Thériault, Defence Research and Development Canada, Valcartier (Canada); P. Lacasse, AEREX avionique inc. (Canada); F. Bouffard, H. Lavoie, E. Puckrin, S. Desilets, Defence Research and Development Canada, Valcartier (Canada); Y. Montembeault, V. Farley, Telops (Canada)

The passive standoff detection of vapors from particular explosives and precursors emanating from a location under surveillance can provide early detection and warning of illicit explosives fabrication. DRDC Valcartier recently completed the development and field-validation of a novel R&D prototype, MoDDIFS (Multi-Option Differential and Imaging Fourier Spectrometer) to address this security vulnerability. The proposed methodology combines the clutter suppression efficiency of the differential detection approach with the high spatial resolution provided by the hyperspectral imaging approach. This consists of integrating the imaging capability of the Hyper-Cam IR imager with a differential CATSI-type sensor. The MoDDIFS sensor includes two configuration options:

option 1 for remote gas detection, and option 2 for polarization sensing of surface contaminants.

In this paper, we will first review the basic phenomenology associated with the infrared spectral detection of gas and liquid contamination. Second, initial gas tests done with MoDDIFS on F-152a, diethyl ether and several other vapour releases will be analyzed and discussed. Finally, surface contaminant detection tests done with ethylene glycol will serve to demonstrate a new capability for surface contamination sensing by spectral polarization subtraction.

8358-25, Session 5

Possibilities for standoff Raman detection applications for explosives

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This paper provides a brief overview of the Raman based standoff detection methods developed at the Swedish Defence Research Agency for the purpose of standoff explosives detection. The methods concerned are Raman imaging for particle detection and resonance enhanced Raman spectroscopy for vapour detection.

These methods are today reaching a maturity level that makes it possible to consider applications such as trace residue field measurements, on site post blast analysis and other security of explosives related applications.

The paper will look into future possible applications of these technologies. Our group has extensive activities in applications of the technology, in projects for the Seventh Framework Program of the European Union as well as for other clients. Some of these possible applications will be described and a look into future development needs will be made.

As far as possible, applicability will be discussed with a view on realistic explosives trace availability for detection. Necessary data to make such realistic applicability assessment is not always available and a brief discussion on the applicability of using the developed Raman technology to obtain this kind of data will also be made.

Making the transition from research to practical applications considerations of eye-safety of the system must be made. This aspect will also be considered.

8358-26, Session 5

Coded-aperture Raman imaging for standoff explosive detection

S. McCain, B. Guenther, Applied Quantum Technologies, Inc. (United States)

This paper describes the design of a deep-UV Raman imaging spectrometer operating with an excitation wavelength of 228 nm. The designed system will provide the ability to detect explosives (both traditional military explosives and home-made explosives) from standoff distances of 1-10 meters with an interrogation area of 1 mm x 1 mm to 200 mm x 200 mm. This excitation wavelength provides resonant enhancement of many common explosives, no background fluorescence, and an enhanced cross-section due to the inverse wavelength scaling of Raman scattering. A coded-aperture spectrograph combined with compressive imaging algorithms will allow for wide-area interrogation with fast acquisition rates. Coded-aperture spectral imaging exploits the compressibility of hyperspectral data-cubes to greatly reduce the amount of acquired data needed to interrogate an area. The resultant systems are able to cover wider areas much faster than traditional push-broom and tunable filter systems. The full system design will be presented along with initial data from the instrument. Estimates for area scanning rates and chemical sensitivity will be presented. The system components include a solid-state deep-UV laser operating at 228 nm, a spectrograph consisting of well-corrected refractive imaging optics and a reflective grating, an intensified solar-blind CCD camera, and a high-efficiency collection optic.

8358-27, Session 5

Coherent anti-stokes Raman spectroscopy for detecting explosives in real time

A. Dogariu, Princeton Univ. (United States); A. Pidwerbetsky, LGS Innovations Inc. (United States)

Raman spectroscopy is a very useful tool for identifying target molecules based on their specific vibrational signatures. Remote detection of trace amounts of explosives is made difficult by the very low efficiency of the spontaneous Raman process. We demonstrate more than five orders of magnitude enhancement by using collinear, backscattered Coherent Anti-Stokes Raman Spectroscopy (CARS). Using a hybrid time-resolved broad-band CARS we identify nanograms of explosives on the millisecond time scale. The broad-band excitation in the near-mid infrared region excites the vibrational modes in the fingerprint region, and the time-delayed probe beam ensures the reduction of any non-resonant contributions to the CARS signal. The strong coherent enhancement allows for recording Raman spectra in real-time. We demonstrate stand-off detection by acquiring, analyzing, and identifying vibrational fingerprints in real-time with very high sensitivity and selectivity.

By extending the focused region from a 100-micron sized spot to a 5mm long line we can obtain the spectral information from an extended region of the remote target with high spatial resolution. We demonstrate fast hyperspectral imaging by one-dimensional scanning of the Line-CARS. The two-dimensional image contains the vibrational spectra of the target in each pixel, allowing for chemical mapping of the remote target.

8358-28, Session 5

Smart multiple explosives detection and identification using surface plasmon-coupled emission

S. Ja, ICx Nomadics, Inc. (United States)

To fight against the explosives-related threats in defense and homeland security applications, a smarter sensing device that not only detects but differentiates multiple true threats from false positives caused by environmental interferents is essential. The existing trace explosives vapor detection platforms that use single fluorescence reporter, such as FLIR's Fido XT explosive detector, has achieved a femtogram-level detection limit to TNT, but the identification, interferent rejection capability, and wider-range explosives detection capability was limited. A new optical detection system is proposed to address these issues by using the temporal and spectroscopic information generated by the surface plasmon coupling emission (SPCE) effect. Innovative SPCE optics has been designed using Zemax software to project the fluorescence signal into a beautiful "rainbow rings" on a CCD with sub-nanometer wavelength resolution. The spectroscopic change of the fluorescence signal and the time history of the change due to the presence of a certain explosive analyte has found unique and can be used to identify explosives and interferents. Thanks to the extremely high optical efficiency, reporter deposition as small as 160-µm in diameter can generate enough signal so that an array of different reporters can be interrogated with wavelength multiplexing to detect wide range of explosives. We have demonstrated detection and classification of explosives, such as TNT, NT, NM, RDX, PETN, and AN, with multiple sensing materials in a prototype.

8358-30, Session 6

Photo-assisted electrochemical detection (PAED) following HPLC-UV for the determination of nitro explosives and degradation products

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Nitro explosives developed at munitions sites provide the pathway for contaminating the environment and its surroundings. Microorganisms present in the environment have the potential to degrade explosives to carcinogenic and toxic products in soil and groundwater. This presents the possibility for accidental exposure to humans and wildlife and initiates the need to monitor these compounds due to toxicological concern. The overall goal of this project is for the bioremediation of contaminated sites.

Photo-assisted electrochemical detection (PAED) following HPLC-UV is applied for the determination of RDX and RDX degradation products in environmental matrices. Specifically, analytes of interest are N-nitroso degradation products MNX, DNX, TNX as well as ring cleavage product methylene dinitramine (MEDINA). Environmental samples provided by the United States Geological Survey (USGS) will be used to highlight the analytical utility of the method. Projected results of this research include a validated analytical method, which may be applied commercially to several bioremediation projects targeted for the removal of RDX and degradation products from the environment. The improvements sought after in optimizing the separation and detection of these compounds are anticipated to yield a competitive method of detection to existing analytical techniques.

8358-31, Session 6

Investigating a drop-on-demand microdispenser for standardized sample preparation

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The existing assortment of reference sample preparation methods presents a range of variability and reproducibility concerns, making it increasingly difficult to assess chemical detection technologies on a level playing field. We are investigating a drop-on-demand table-top printing platform which offers precise liquid sample deposition and is well suited for the preparation of effective reference materials. Current research includes the development of a sample preparation protocol for explosive materials testing based on drop-on-demand technology. Device settings are determined for optimal droplet formation and velocity. Droplet diameter and uniformity were measured using ultraviolet-visible (UV-Vis) absorption and Raman spectroscopy. The results presented here demonstrate the operational factors that influence droplet dispensing for specific materials (e.g. energetic and interferents). Understanding these parameters allows for the investigation of droplet and sample uniformity and reproducibility (typical calibration goodness of fit R2 values of 0.991, relative standard deviation or RSD $\leq$ 5%), and thus the development of a successful and robust methodology for energetic sample preparation.

8358-32, Session 6

Ion mobility spectrometry for detection of explosives, taggants, and related materials using an existing, fielded chemical agent detector: the M4A1-JCAD

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In the continuing effort to mitigate the effects of “Improvised Explosive Devices” Army Technology Objective “Detection of Unknown Bulk Explosives” has been established. Fielded, hand-held point sampling chemical warfare agent (CWA) detectors are being evaluated for detection of explosives and related materials. All automatic point sampling CWA detectors in the U.S. military are based on Ion Mobility Spectrometry (IMS) - M4-JCAD, M22-ACADA and I-CAM. The work assesses the extent to which the M4-JCAD can be applied to detecting explosives without hardware modifications and assesses sample introduction techniques that minimize hardware modifications.

Explosives and related materials include di-nitrotoluene (DNT), tri-nitrotoluene (TNT), pentaerythritol-tetranitrate (PETN), ethylene-glycol-dinitrate (EGDN), ammonium-nitrate, and dimethyl-dinitrobutane (DMNB) - C-4, “pure” RDX are planned. Less than 10 parts-per-billion have been detected with signal-to-noise ratios indicating at least an order of magnitude reduction in limit of detection (LoD) without hardware modifications. LoDs are orthogonally validated using GC-MS analytical techniques.

To provide explosives detection capabilities using CWA detectors, with only software and firmware modifications, false alarms are addressed. Accurate and precise ion mobility constants are being obtained for target compounds vs. temperature, electric field strength, and drift gas water concentration in positive and negative ionization modes - accuracy of measurements is an order of magnitude better than literature values. Parametric measurements are made using commercial NIST-traceable sensors. Ion mobility constants are determined using a hybrid IMS-time-of-flight mass spectrometer for high resolution product ion identification. Accurate, precise ion mobility constants result in narrowing detection spectrum windows to reduce potential for false alarms without affecting detection sensitivity.

8358-33, Session 6

Multi-dimensional detection of explosives and explosive signatures via laser electrospray mass spectrometry

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The diversity of possible signature molecules and their inherent low vapor pressures make the detection of explosives in an asymmetric threat scenario a great challenge. Complex environmental interactions and clutter in the background make the threat detection problem seemingly impossible. A newly discovered release and detection technology can enable discrimination of threat signatures in complex backgrounds by utilizing intense, nonresonant, ultra-short laser pulses to nonlinearly couple into “fragile” molecules adsorbed onto a surface. The nonresonant femtosecond laser pulse increases the vapor pressure of the adsorbed threat agent (e.g. biological, chemical or explosive) by approximately 8 orders of magnitude. This increase in vapor pressure allows for analysis of the gas phase molecules through the use of electrospray post-ionization mass spectrometry, enabling both point and remote detection.

Investigations using low vapor pressure molecules led to the discovery that the adsorbed species is transferred, without decomposition, into the gas phase via a nonthermal mechanism. The nonresonant, femtosecond laser vaporization with electrospray post-ionization technique has allowed for the mass analysis and classification of trace amounts of nitro-based, peroxide-based and inorganic-based explosives from a variety of operationally significant substrates (e.g. steel, glass, cloth, sand and wood). The vaporization of unfragmented molecules from a surface and the use of multivariate statistical methods facilitate the identification and classification of the threat agent, reducing the probability of false positives and false negatives.

8358-34, Session 6

Silica-anchored fluorescent organo-silicon polymers for explosives separation and detection

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The luminescent organosilicon copolymers poly(silafluorenyldiethynylspirobifluorene) and poly(silolediethynylspirobifluorene) have been covalently linked to a thin layer chromatography (TLC) support through the use of a trimethoxysilyl end group. Surface functionalization of silica with the fluorescent sensing polymer allows for more efficient quenching by anaylte, due to the small amount of fluorophore present, thus yielding enhanced detection sensitivity. The attachment of the sensing polymers onto a chromatographic support also allows for simultaneous separation of an explosive mixture, and component identification through the use of multiple sensing polymers. In a 1 mm2 area solution spotted onto the fluorescent silica plate, detection limits obtained for the explosives TNT (2,4,6-trinitrotoluene), DNT (2,6-dinitrotoluene), PA (picric acid), Tetryl (N-methyl-N,2,4,6-tetranitroaniline), HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine), RDX (1,3,5-trinitro-1,3,5-triazacyclohexane), and CI-20 (2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaisowurtzitane) ranged from 4 to 750 pg/mm2. Since less than 350 pg of highly fluorescent polymer is required to coat each TLC plate, the relatively small amounts of explosive being detected still represent an excess of quencher over fluorophore. The performance of these materials will also be discussed with respect to colorimetric detection and field usable detection platforms. Part of this work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8358-35, Session 6

Portable thin layer chromatography (TLC) for field detection of explosives

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There are several methods for explosives detection in the field, from simple color-imetric kits to sophisticated spectroscopic methods. All these methods define some type of explosives detection-from screening to speciation of the exact material. One such technology that is mature for laboratory use, but performs very well is thin layer chroma-tography (TLC). TLC is fairly simple, has few power requirements, is very accurate in separation and detection, and can have very low limits of detection.

A new miniaturized, bench prototype, field portable thin-layer chromatography (micro-TLC) kit for the detection and identification of common military explosives has been demonstrated in a laboratory environment and is ready for field testing. The kit is comprised of a low cost set of commercially available components specifically assembled for rapid identification needed in the field. The kit utilizes aluminum backed reverse-phase C18 TLC plates (RP-18) to separate and identify the common military explosives: HMX, RDX, Tetryl, Explosive D or picric acid, and TNT all on one plate. The kit makes use of smaller pre-cut (~1" x 2") plates that are pre-spotted with explosives standards eliminating the need to apply standards in the field. These pre-spotted standards remain viable for greater than 1 year. By employing these smaller pre-spotted plates, the entire unknown sample collection, spotting, developing, and identification process can be done in about 3 minutes or less.

This work was performed under the auspices of the U. S. Department of Energy by Law-rence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8358-36, Session 6

Silicone-hydrogels as immobilization matrices for enzyme-based sensors: optochemical detection of peroxide explosives and their precursors

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Detection of gaseous peroxides in ambient air is an important subject to detect peroxide-type explosives such as triacetone triperoxide (TATP). Therefore a sensitive and rapid detection method for peroxides is desirable, which is not limited to liquid and solid samples. The high loss of mass by sublimation allows the detection of such explosives in the gas phase, even decomposition by UV will be needed to form hydrogen peroxide.

We present a new optical polymer thin film sensor for high sensitivity and rapid response detection of gaseous hydrogen peroxide. The sensor consists of a silicone-containing amphiphilic co-network (APCN), referred to as silicone hydrogel, in which the enzyme horseradish peroxidase and ABTS as chromophor has been embedded. Due to the unique properties of the APCNs, accurate detection of hydrogen peroxide at the ppm level is feasible within seconds.

Silicone hydrogels are copolymeric two-component networks consisting of hydrophilic and hydrophobic phases. These contrary phases build covalently co-connected networks and form nanophase-separated areas. This co-continuous morphology and the small dimensions of separation in the silicone hydrogel lead to a great inner surface. Due to the large interface between the phases - in bulk and surface - and the high gas permeability (silicone phase), a short response time results for detection in the ppm range for gas phase hydrogen peroxide.

Here, we describe the enzymatic detection of hydrogen peroxide in a silicone hydrogel thin film within seconds as a prototype for detection of gaseous peroxides.

The sensor films were prepared by copolymerization of 2-dimethylaminoethyl acrylate (DMAEA) with the macromonomer α,ω-dimethacryloxymethyl-polydimethylsiloxane (MA-PDMS-MA) on a previously methacrylate-modified glass slide, Sensor synthesis is completed by loading the thin film with horseradish peroxidase/ABTS in PBS and allowed to dry, leaving the enzyme and ABTS immobilized in the PDMAEA phase.

Measurements were taken in a modified UV-VIS spectrophotometer at several H2O2 concentrations. The H2O2 concentrations were set by evaporation of aqueous H2O2 solutions into a stream of carrier air. The calibration is based on the well-defined vapour pressure of hydrogen peroxide over binary mixtures of hydrogen peroxide and water at defined temperatures.

The linear fit of the slope between two setting points of the detected absorbance leads to a maximum slope within the first seconds. In the presented case the slope was evaluated for the period between 15 and 25 seconds, due to the high linearity in this range. Accurate detection within 25 sec for H2O2 concentrations down to 1 ppm were achieved.

8358-37, Session 6

Portable standoff Raman system for fast detection of homemade explosives through glass, plastic containers, and water

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At the University of Hawaii, we have been developing portable remote

Raman systems capable of detecting chemicals in daylight from a safe standoff distance. We will present Raman data on standoff detection of chemicals used in synthesis of homemade explosives (HME) using a portable standoff Raman system utilizing a directly coupled 8-inch telescope. Data shows that good quality Raman spectra of various hazardous chemicals such as ammonium nitrate, potassium nitrate, potassium perchlorate, sulfur, nitrobenzene, benzene, acetone, and various organic and inorganic chemicals could easily be obtained from remote distances, tested up to 120 meters, with a single laser shot and with detection time less than 1 μs. Our new system uses a frequency-doubled Nd:YAG pulsed laser source (532 nm, 100 mJ/pulse, 15 Hz, pulse width 8 ns) capable of firing a double pulse. The double pulse configuration also allows the system to perform standoff LIBS at 50 m range. In the standoff Raman detection, the double pulse sequence simply doubles the signal to noise ratio. Significant improvement in the quality of Raman spectra is observed when the standoff detection is made with 1 s of integration time firing 30 laser shots at 15 Hz. The system uses a 50 micron slit and has spectral resolution of 8 cm-1. The HME chemicals could be easily detected through clear and brown glass bottles, plastic containers and also through water. Possible applications of the standoff Raman system for homeland security and environmental monitoring will be discussed.

8358-38, Session 7

Reduced LIBS plasma model via thermodynamics

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A standard spectroscopic sensor technique for classification of materials is Laser Induced Breakdown Spectroscopy (LIBS). Though LIBS, as an Atomic Emission Spectroscopy (AES) technique, is generally separated from signal processing based classification techniques, they strongly interact in the design of sensor systems. Strict disciplinary separation results in approaches that inadequately address the mass, power consumption and other portability parameters of the ultimate sensor. Modifications in the sensor design approach and of the classification processing techniques, reduce redundancies in the system, resulting in more compact overall systems. Use of an engineering thermodynamic approach to the plasma description, as part of a predictor-corrector style classification loop, is used to reduce system requirements for material classification. This paper presents results for the compaction of the model system. In this work, a non-traditional approach is made to reduce the modeling system to a configuration compatible with the incorporation of the model onto a compact DSP structure. Calculation of partition function tables, allows heuristic adjustments to a thermodynamic description of the LIBS plasma. Once the plasma environment is established, rate equation descriptions can establish detailed balance and predict the emission properties of the sample. The resulting model must be compatible with compact, low power, computation schemes, such as multi-core DSP's as part of a predictor-corrector classifier.

8358-39, Session 7

Real-time residue and powder analysis with laser-assisted infrared imaging

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First responders have the need to quickly assess a situation; Understanding if there are biological or explosive hazards present can influence a plan of action. The need for real-time information, however, precludes most laboratory analysis techniques. The requirement of not disturbing a sample until it is understood makes the problem even more challenging. Visual identification can go a long way in assessing a threat, and now technologies in the mid-infrared (2 to 20 μm) spectral region allow extending that “vision” into a spectral region known for its chemical identification capabilities. This paper considers the fusion of tunable quantum cascade lasers with infrared focal plane arrays to create a true chemical imager. Instrumentation is developed that allows real-time chemical analysis of residues and powders in a non-contact fashion. Identification of explosive residues and biological powders are considered as examples of use of this new technology for first responders. As opposed to many fielded technologies that allow only point detection of substances, and often require many seconds to analyze a sample, mid-infrared chemical imagers provide context in addition to sample analysis in real time. They are also ideal for image fusion techniques combining visual images with chemical images from an infrared multispectral analysis. This type of chemical overlay on live video provides first responders with a powerful tool for rapid threat assessment.

8358-40, Session 7

Non-contact detection of trace materials using infrared lasers

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We have developed two techniques for non-contact detection of trace analytes (explosives, chemicals, drugs, etc.) on surfaces using infrared quantum cascade lasers tuned to wavelengths that couple strongly with the vibrational absorption modes of the target material. The first technique uses modest, eye-safe laser powers to raise the temperature of the target material approximately 1 °C, which is then detected by photo-thermal imaging. We have demonstrated the technique at several meters of stand-off distance indoors and in field tests. Sensitivity to explosive traces as small as a single grain (~1 ng) has been demonstrated. By varying the laser wavelength we can increase the specificity between materials, even those with similar absorption profiles. Our second technique uses higher laser intensities to heat the target material by tens of degrees to increase its vapor pressure. The instantaneously generated vapor can be evaluated by any number of detection techniques which can accommodate vapor sampling or spectroscopic analysis; here we present results using an ion mobility spectrometer in close proximity (~2 cm) to the sample to detect explosive materials including RDX and TNT. We find that the technique generates vapor with all tested substrates, though the thermal and spectroscopic properties of the substrate affect the extent of the enhancement.

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Reference: R. Furstenberg et al. Applied Physics Letters 93, 224103 (2008).

8358-41, Session 7

Highly efficient SERS substrates based on filter paper loaded with plasmonic nanostructures

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We report a novel surface enhanced Raman Scattering (SERS) substrate platform based on a common filter paper adsorbed with plasmonic nanostructures that overcomes many of the challenges associated with existing SERS substrates. The paper-based design results in a substrate that combines all of the advantages of conventional rigid and planar SERS substrates in a dynamic flexible scaffolding format. Here, we will discuss the fabrication, physical characterization and SERS activity of our novel substrates using non-resonant analytes. The SERS substrate was found to be highly sensitive, robust, amiable to several different environments and target analytes. It is also cost-efficient, and demonstrates high sample collection efficiency and does not require

complex fabrication methodologies. The paper substrate has high sensitivity (0.5nM BPE) and excellent reproducibility (~15% RSD). The paper substrates demonstrated here establishes a novel platform for integrating SERS with already existing analytical techniques such as chromatography and microfluidics, imparting chemical specificity to these techniques.

8358-42, Session 7

Next-generation surface-enhanced Raman scattering (SERS) substrates for hazard detection

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Sensitive, accurate and reliable methods are needed for the detection and identification of hazardous materials (chemical, biological, and energetic) in field. Utilizing such a sensing capability incorporated into a portable detection system would have wide spread beneficial impact to the U.S. military and first responder communities. Surface enhanced Raman scattering (SERS) is increasingly becoming a reputable technique for the real-time, dynamic detection and identification of hazard materials. SERS is particularly advantageous as it does not suffer from interferences from water, requires little to no sample preparation is robust and can be used in numerous environments, is relatively insensitive to the wavelength of excitation employed and produces a narrow-band spectral signature unique to the molecular vibrations of the analyte.

We will report on the characterization and sensing capabilities of these next generation SERS substrates using known SERS active chemicals. Furthermore, the utilization of these substrates for the detection of energetic materials (e.g., ammonium nitrate (AN), RDX, TNT, PETN) will be demonstrated. Producing highly uniform samples, known concentrations of energetic materials are jet printed onto the SERS sensing surface using a precisely calibrated MicroJet system. Additionally, preliminary efforts toward the development of an innovative biomimetic SERS sensing platform will be discussed. This novel platform employs tailored peptides recognition elements (e.g., TNT, biological hazards) for the specific capture of known targets.

8358-43, Session 7

Femtosecond fiber-laser-based laser-induced breakdown spectroscopy

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This paper reports the studies on elemental composition detection and identification using laser induced breakdown spectroscopy (LIBS) system by employing a femtosecond fiber laser. Femtosecond laser pulses have the advantages of high peak irradiance, thus lower the ablation threshold. High quality LIBS spectra were obtained using near-infrared femtosecond fiber laser coupled with a high throughput spectrograph and a high sensitivity non-gated detector. Specific ion and neutral emission lines of different materials have been characterized, including Ti, Al, Fe, Cu, brass and glasses. Different laser parameters including fluence, repetition rate, scanning speed and integration time have been studied to enhance the signal to background ratio. Results show that faster scanning speed can enhance the signal to background ratio and decrease the integration time, and the obtained spectra is highly reproducible at different repetition rates up to 1 MHz. Different wavelengths by second or third harmonic generation of the fs fiber laser have been used to observe the pulse wavelength effect on the plasma emission and the quality of the obtained spectra. Compared with conventional LIBS, femtosecond fiber laser have advantages of less sample heating and damage, better spatial resolution and signal to background ratio, compact, reliable and cost-effective. This shows a potential of building compact, low-cost and robust detection system for versatile and rapid analysis of chemical and special explosive materials.

8358-44, Session 7

Nondestructive detection and imaging of trace chemicals with high-chemical specificity using single-beam coherent anti-stokes Raman scattering in a standoff configuration

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The excellent chemical identification ability of Raman based spectroscopy provides a versatile and widely applicable method to identify hazards within a complex chemical environment. Raman spectroscopy has been shown effective in standoff detection of small quantities of explosives at large standoff, however, the ability to detect trace quantities is limited due to the low Raman scattering cross section. Coherent anti-Stokes Raman scattering (CARS) provides the same chemical specificity, but with much greater signal due to coherent addition in the non-linear spectroscopy. Utilizing CARS, we have demonstrated µg/cm2 level detection of an explosive simulant using a single laser producing less than 8mW of laser power in the near IR. Further, this detection level was achieved on a simulant present as only a small part within a polymer mixture, showing great promise for real world detection of trace quantities of potential hazards. We will present standoff chemical images of trace compounds within a complex chemical environment, which effectively demonstrate the unique capabilities of the method.

8358-45, Session 7

Time evolution of infrared signatures of chemicals on outdoor surfaces

A. K. Goyal, M. Spencer, E. C. Wack, A. Sanchez, MIT Lincoln Lab. (United States)

A critical need exists to detect and identify chemical warfare agents (CWAs) on surfaces with high areal coverage rates. A promising technique to achieve this is active long-wave-infrared (LWIR) hyperspectral imaging in which chemicals are identified based on strong and unique absorption features in the wavelength band from 3 to 14 microns. The concept involves illuminating the scene with a wavelength-tunable laser and imaging the scene with a focal plane array (FPA) at each illumination wavelength to generate a hyperspectral image-cube. The presence of chemicals is determined based on the spectrum of the optical return for each pixel or group of pixels. Previously, we reported very encouraging results that demonstrated that active LWIR hyperspectral imaging can be used to identify chemicals on realistic outdoor surfaces such as asphalt, concrete, and sand. Since these outdoor surfaces are highly porous, the spectral signatures are expected to decrease in strength with time. In the present work, we investigate the time-evolution of the LWIR spectral signatures and correlate these with estimates for the surface concentration of the chemical. The chemical simulant used was diethyl phthalate (DEP). It was applied to a variety of realistic outdoor surfaces. LWIR hyperspectral images were obtained as a function of time using a wavelength-tunable quantum-cascade-laser (QCL) and a custom HgCdTe FPA camera. These results will support modeling of the signature phenomenology and agent/substrate interaction.

8358-46, Session 7

Improved sensing using simultaneous deep-UV Raman and fluorescence detection

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(United States)

This paper addresses the need to increase sensitivity and specificity for miniature real-time sensors for trace levels of biological, chemical, and explosives materials. The method discussed uses simultaneous detection of Raman and fluorescence emissions excited in the deep UV between 220 and 250 nm.

There are four main advantages of excitation in the deep UV compared to near-UV, visible or near-IR counterparts. 1) Excited between 220 and 250 nm, Raman emission occur within a fluorescence-free region of the spectrum, eliminating obscuration of weak Raman signals by fluorescence from target or surrounding materials. 2) Because Raman and fluorescence occupy separate spectral regions, detection can be done simultaneously, providing a much wider set of information about a target. 3) Rayleigh law and resonance effects increase Raman signal strength and sensitivity of detection. 4) Penetration depth into target in the deep UV is short, providing separation of a target material from its background or substrate.

The evolving sensor can discriminate CBE from background materials using a combination of deep UV excited Raman and fluorescence emissions. Raman spectroscopy is a method that provides information about molecular bonds, while fluorescence spectroscopy is a much more sensitive method that provides information regarding the electronic configuration of target molecules. Photon Systems, in collaboration with JPL, has been developing combined Raman and fluorescence methods for over 9 years, focused on the advantages of excitation in the deep UV below 250nm.

8358-47, Session 7

Stand-off CWA imaging system: second sight MS

P. F. Bernascolle, A. Elichabe, F. Fervel, J. Haumonté, Bertin Technologies (France)

In recent years several manufactures of IR imaging devices have launched commercial models that are applicable to a wide range of chemical species. Bertin Technologies, has developed a stand-off gas imaging system using a multi-spectral infrared imaging technology. With this system, the gas cloud size, localization and evolution can be seen in real time.

The goal was to meet the requirement for an early warning caused by a chemical threat. With a night and day efficiency of up to 5 km, this process is able to detect CWA, TIC and flammable gases.

Second Sight MS is the only, in series produced, passive stand-off CWA imaging system with a wide field of view (up to 60°), already order by several regulars armies.

This paper examines this IR gas imager's performance when exposed to several CWA, TIC and simulants compounds.

First, we will describe the Second Sight MS system. The theory of the gas detection, visualization and classification functions have already been described elsewhere, so we will just summarize it here. Second, the main topic of this paper, we present the results of the tests done in laboratory on live agents and in open field on simulants. The sensitivity threshold of the camera measured in laboratory, on some live CWA (G, H agents...) and TIC (ammonia, sulfur dioxide...) will be given. The result of the detection and visualization of a gas cloud in open field testing for some stimulants (SF6, DMMP) at a far distance will be also shown.

8358-48, Session 8

Selective cavity enhanced trace gas detection via diffusion time-of-flight spectrocopy

A. Miller, J. McKeever, C. R. Viteri, B. Richman, Entanglement Technologies, Inc. (United States)

A novel approach to optical detection of airborne explosive vapor using a combination of cavity enhanced absorption spectroscopy and diffusion time of flight is reported. The direct optical detection of explosive vapors by absorption presents a number of unique challenges due to low vapor pressures of explosive compounds, a lack of resolved spectral features, and the presence of interfering species with overlapping absorption spectra. By recording the changing optical absorption as sampled atmosphere diffuses into an explosive-free buffer gas, the concentration of explosive molecules may be determined using a Bayesian statistical signal processing technique. This technique avoids the need for laser wavelength scans while simultaneously providing robust background rejection. The use of fixed laser wavelengths allows for the use of cavity-locked cavity ring-down or cavity-locked direct cavity transmission absorption measurements with high data acquisition rates and significantly reduces the complexity of the laser system by eliminating the need for precision wavelength monitoring. This allows for the development of compact, field deployable sensors based on this technique. Experimental demonstration of the simultaneous detection of multiple species of hydrocarbon tracer molecules at 4295/cm will be reported.

8358-49, Session 8

Detection of trace gases using frequency modulated off-axis cavity ring-down spectroscopy

A. Karpf, G. N. Rao, Adelphi Univ. (United States)

A trace gas sensor based on frequency modulated, off-axis cavity ring down spectroscopy has been developed to detect and measure the concentration of atmospheric contaminants (e.g., explosive vapors, pollutants, etc.). Off-axis alignment leads to a dense cavity mode structure making it less sensitive to vibration and optical feedback to the laser, and removing the need for triggering electronics used with frequency or cavity swept CRDS. If the off-axis alignment does not result in a true continuum of cavity modes, the intensity of the light exiting the cavity can have a significant dependence on laser frequency leading to large fluctuations in CRD decay amplitude (a significant problem for lasers that are not frequency stabilized or actively locked). Frequency modulation and averaging over multiple CRD decays results in an effectively continuous mode structure resulting in a stable CRD signal. We demonstrate the technique using an external cavity quantum cascade laser which did not have an active feedback system to lock to a specific line, and thus drifted slowly over a small (0.01 cm 1) region around the target frequency. Without frequency modulation, significant fluctuations in the CRD decay amplitude (including periods at which there was no detectable CRD signal) were observed. The present approach was demonstrated by detecting NO2 in Zero Air with a sensitivity of 1.5 ppb; this is about 2 to 3 times the magnitude expected for CRD without mode-matching. However, the sensor's reduced sensitivity to vibrations and simplified design should make it a candidate for field-based trace gas detection.

8358-50, Session 8

Lightweight autonomous chemical identification system (LACIS)

G. Lozos, Smiths Detection Edgewood (United States); H. Lin, T. Burch, Intelligent Optical Systems, Inc. (United States)

Smiths Detection and Intelligent Optical Systems have developed the Lightweight Autonomous Chemical Identification System (LACIS) for the US Department of Homeland Security. LACIS is a handheld detection system for Chemical Warfare Agents (CWAs) and high priority Toxic Industrial Chemicals (TICs). LACIS is designed to have a low limit of detection and rapid response time to provide emergency responders with a tool to determine whether areas have dangerous concentration levels and if protective garments will be required. Current procedures for physical protection of responders to hazardous materials incidents require the use of protective equipment until such time as the hazard can be assessed. LACIS will be used to accelerate operations and increase their effectiveness.

LACIS is an improved point detector employing novel CBRNE detection modalities that includes a military-proven ruggedized ion mobility spectrometer (IMS) with an array of electro-resistive sensors to extend the range of chemical threats detected in a single device. It uses a novel sensor data fusion and threat classification architecture to interpret the independent sensor responses and provide robust detection at low levels in complex backgrounds with minimal false alarms.

The performance of LACIS has been characterized extensively in company tests and in independent 3rd party laboratory tests at the Battelle Memorial Institute (Columbus, OH) and in 3rd party indoor and outdoor field tests at the Nevada Test Site (NTS). LACIS is now entering operational assessment by key government emergency response groups to confirm it meets the requirements for federal, state and local emergency responders.

8358-51, Session 8

Spatiotemporal sampling of diffusion processes on meshes and networks

Y. M. Lu, Harvard Univ. (United States)

Consider the distributed spatiotemporal sampling of diffusion fields (e.g., temperature variations, chemical substance distributions) by a network of sensors. The basic questions are the following: Suppose we observe a spatiotemporal process governed by the diffusion equation and driven by some unknown sparse sources. To perfectly reconstruct the field, or to reliably estimate the sources, how many sensors do we need, where do we place them in space, and how often should each sensor sample in time?

We study the fundamental limits and tradeoff of the above sampling problem, and present reconstruction algorithms. In particular, we will show that, by exploiting the spatiotemporal correlation offered by the diffusion equation, it is possible to achieve a rigorous trade-off between the required spatial and temporal sampling densities. Specifically, by oversampling and processing in time, we can significantly improve the spatial resolution of the reconstructed field, even though the spatial density of the sensors is sub-Nyquist, thus allowing super-resolution in space.

Finally, we will highlight the applications of these results in localizing sources on large finite element meshes and general networks.

8358-52, Session 8

A microfluidic toolbox approach to CBRNE sensing

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Microfluidics has proven to be a very effective technology for the identification of biological and chemical analytes in a CBRNE scenario. The required process steps however are manifold, making the development of an integrated microfluidic device which includes all necessary analytical process steps in a single device a complicated project with a high level of technological risk. In order to minimize this development risk, we present a toolbox approach to this problem. The complex analytical process is broken down into functional unit operations such as sample uptake, lysis of bacterial or viral material, nucleic acid extraction, amplification and detection. These unit operations are realized as microfluidic modules in a standard format (usually microscopy slide) and with standardized microfluidic interfaces, allowing a validation of the functionality of these individual units with comparatively little effort. After functional module validation, the individual functions can then be integrated into a single microfluidic device. We will demonstrate this process with application examples from the detection of simple disease cases such as coeliac disease to the multiplex detection of pathogens like yersinia pestis et al. In addition, the requirements and examples for instrumentation driving such integrated lab-on-a-chip systems will be demonstrated.

8358-53, Session 8

Advances in field-portable ion-trap GC/MS instrumentation

E. Diken, J. Arnó, E. Skvorc, D. Manning, G. Andersson, K. Judge, K. Fredeen, Smiths Detection (United States); C. Sadowski, Torion Technologies, Inc. (United States)

The rapid and accurate detection and identification of chemical warfare agents and toxic industrial chemicals can be critical to the protection of military and civilian personnel. The use of gas chromatography (GC) - mass spectrometry (MS) can provide both the sensitivity and selectivity required to identify unknown chemicals in complex (i.e. real-world) environments. While most widely used as a laboratory-based technique, recent advances in GC, MS, and sampling technologies have led to the development of a hand-portable GC/MS system that is more practical for field-based analyses. The unique toroidal ion trap mass spectrometer (TMS) used in this instrument has multiple benefits related to size, weight, start-up time, ruggedness, and power consumption. Sample separation is achieved in record time (~3 minutes) and high resolution using a state of the art high-performance low thermal mass GC column. In addition to providing a system overview highlighting its most important features, the presentation will focus on the chromatographic and mass spectral performance of the system. Algorithmic advances in mass calibration, baseline correction, peak identification, deconvolution, and library searching will also be described. Finally, results from exhaustive performance testing of the new instrument will be introduced to validate its unique robustness and ability to identify unknown chemicals.

8358-54, Session 8

Photoacoustic spectroscopy for chemical sensing

E. L. Holthoff, P. M. Pellegrino, U.S. Army Research Lab. (United States)

The Global War on Terror has made rapid detection and identification of chemical and biological agents a priority for Military and Homeland Defense applications. Reliable real-time detection of these threats is complicated by our enemy's use of a diverse range of materials. Therefore, an adaptable sensor platform is necessary. Development of a sensor that will meet the Army's requirements for an inexpensive, portable, highly sensitive and selective system, with minimal power consumption is a difficult task.

Photoacoustic spectroscopy (PAS) is a useful monitoring technique that is well suited for trace detection of gaseous and condensed media. This method routinely exhibits detection limits at the parts-per-billion (ppb) or sub-ppb range. PAS also possesses favorable detection characteristics when the system dimensions are scaled to a micro-system design. Current research utilizes quantum cascade lasers (QCLs) in combination with micro-electromechanical systems (MEMS)-scale photoacoustic cell designs for trace gas detection. This sensing platform has provided favorable detection limits (ppb) for a variety of chemical species and demonstrated molecular discrimination capabilities. The versatility of PAS has also allowed us to investigate solid and liquid materials using broadly tunable QCLs.

8358-55, Session 8

Real-time quantitative hydrocarbon gas imaging with the gas cloud imager (GCI)

N. A. Hagen, R. T. Kester, Rebellion Photonics (United States)

The gas cloud imager (GCI) is a snapshot LWIR multispectral camera adapted from image mapping spectrometry. While previous image mapping spectrometers have been developed for use in visible light for microscopy, we have adapted the technology for use in the LWIR with uncooled microbolometer array detectors. Because it uses a snapshot spectral imaging technique, the GCI demonstrates an unprecedented light throughput. By implementing a radiometric calibration and analyzing the image with spectral libraries of hydrocarbon gases, this throughput allows the GCI to deliver quantitative images of gas concentration for multiple gas species at 30 frames/sec.

8358-57, Session 8

Photoacoustic spectroscopy (PAS) system for remote detection of explosives, chemicals, and special nuclear materials

H. Chien, K. K. Wang, S. Sheen, A. P. C. Raptis, Argonne National Lab. (United States)

Argonne has developed a practical photoacoustic spectroscopy (PAS) system for open-field remote detection; it integrates the PAS and a novel acoustic resonator (OFAR) techniques. The system can be applied to standoff detection and monitoring of explosives, toxic chemicals and special nuclear materials (SNM). The PAS system consists of a tunable CO2 laser that is modulated by a mechanical chopper and used to excite the targets selectively. The OFAR is a combination of a parabolic reflector and a narrow-band cylindrical acoustic resonator that resonates at the laser modulation frequency. The novel OFAR gives a high signal-to-noise ratio (S/N) and allows one to detect the induced photoacoustic signatures remotely without using a lock-in amplifier. Most toxic chemicals and explosives have specific absorption lines within the CO2 laser emission band, which allows one to identify and quantify the target chemicals or explosives. A theoretical model was developed to predict the resonator performance. An order of improvement in S/N can be achieved by using the resonator. Application to remote detection of target chemicals, such as TNT and ozone, are presented. Unlike a laboratory PAS system, this PAS system can detect chemicals or explosives in an open-field from a distance without sampling, and still keep high sensitivity and spectroscopic selectivity. The system can be an essential instrument for homeland security and defense for detecting and identifying toxic chemicals, roadside bombs, and potentially the SNM. The system can also be used for environmental monitoring, crime scene forensics, and cargo and food inspections.

8358-58, Session 9

Possible standoff detection of ionizing radiation with high-power THz electromagnetic waves

G. S. Nusinovich, C. A. Romero-Talamas, R. Pu, T. M. Antonsen, Jr., V. L. Granatstein, Univ. of Maryland, College Park (United States); P. Sprangle, U.S. Naval Research Lab. (United States)

Recently, a new method of remote detection of concealed radioactive materials was proposed [1]. This method is based on focusing a high-power short wavelength radiation in a small volume of air where the wave electric field exceeds the breakdown threshold and, therefore, in the presence of free electrons an avalanche discharge can be initiated. When the wavelength is short enough, the probability of having even one free electron in this volume in the absence of additional sources of ionization is low. Hence, a high breakdown rate will indicate that in the vicinity of this volume there are some materials causing ionization of air. To prove this concept a 0.67 THz gyrotron delivering 200-300 kW power in 10 microsecond pulses is under development [2]. The range of systems based on using this gyrotron was analyzed [3]. This method of standoff detection of concealed sources of ionizing radiation requires a wide range of studies, e.g., production of free electrons in air by gamma rays penetrating through container walls, statistical delay time in initiation of the breakdown in the case of low electron density, temporal evolution of plasma structure in the breakdown and scattering of THz radiation from small plasma objects. All these issues will be discussed in the paper.

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8358-59, Session 9

Characterization of CdZnTe crystals and radiation detectors

R. B. James, A. E. Bolotnikov, G. S. Camarda, Y. Cui, A. M. Hossain, K. Kim, R. Gul, G. Yang, Brookhaven National Lab. (United States)

Cadmium zinc telluride (CZT) is one of the most promising materials for the production of large-volume X-ray and gamma-ray spectrometers and imaging arrays operable at room temperature. The performance of CZT devices, the global capacity for growth of detector-grade crystals, and the size of the commercial market have progressed steadily over the past 10 years. Because of deficiencies in the quality of the material, commercial high-resolution CZT spectrometers are still limited to relatively small dimensions (1 MeV) and somewhat ineffective for weak radiation signals except in proximity to the source. The detectors are very attractive for a much broader potential range of spectroscopic and imaging applications; however, increases in their efficiency are needed without sacrificing the ability to spectrally resolve gamma-ray energies. To increase the detector efficiency for security applications, the most common method has been to tile separate high-energy-resolution CZT detectors into a suitable mosaic array, although this approach comes at the expense of system cost and complexity. Achieving the goal of low-cost, efficient CZT detectors requires progress in the following areas: better uniformity of detector response, growth of large uniform single crystals, and improved device fabrication procedures. This talk presents the factors limiting the performance of CZT detectors, and it relates the defects observed in the crystals to growth and doping processes. It provides insight into the critical role of small-scale defects on the energy resolution and efficiency of detectors.

8358-60, Session 9

Gamma discrimination in pillar-structured, thermal-neutron detectors

Q. Shao, R. P. Radev, A. M. Conway, L. F. Voss, T. F. Wang, R. J. Nikolic, Lawrence Livermore National Lab. (United States)

The supply shortage of He-3 has triggered research and development of alternative neutron detector technologies. Semiconductor based neutron detectors are one of the most promising technologies. A 20 % efficient solid-state thermal neutron detector based on three dimensional silicon p-i-n diode pillar array filled with Boron-10 was reported by our group [1]. Besides intrinsic neutron detection efficiency, neutron to gamma discrimination is an important figure of merit for unambiguous signal identification. MCNP and COMSOL simulations were conducted to optimize the design of pillar structured thermal neutron detectors in order to obtain large neutron to gamma discrimination while maintaining high thermal neutron detection efficiency. For a given pillar height, neutron to gamma discrimination can be maximized by reducing intrinsic silicon layer thickness below pillars or increasing doping concentration in silicon substrate to reduce the amount of minority carriers which diffuse into intrinsic silicon layer. The neutron to gamma discrimination of pillar detector as a function of incident gamma energy is also discussed. For a 26 μm tall pillar detector, the neutron to gamma discrimination was experimentally measured as high as 1 x 10^7 while maintaining 22 % of thermal neutron detection efficiency with incident gamma energy of 662

keV and low level discriminator of 80 keV.

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8358-61, Session 9

Combined, solid-state molecular property and gamma spectrometers for CBRN&E detection

B. S. Rogers, Nevada Nanotech Systems, Inc. (United States); J. W. Grate, Pacific Northwest National Lab. (United States); B. Pearson, R. Whitten, J. D. Adams, Nevada Nanotech Systems, Inc. (United States)

Nevada Nanotech Systems, Inc. is developing a multi-sensor CBRN&E solution utilizing the Molecular Property Spectrometer (MPS)-a micro-electro-mechanical chip-based technology capable of measuring a variety of thermodynamic and electrostatic molecular properties of sampled vapors and particles-and a compact, high-resolution, solid-state gamma spectrometer module for identifying radioactive materials, including isotopes used in dirty bombs and nuclear weapons.

By conducting a variety of measurements, the system can provide a more complete characterization of an unknown sample, leading to a more accurate identification. Positive identifications of threats are communicated using an integrated wireless module. Currently, system development is focused on detection of commercial, military and improvised explosives, radioactive materials, and chemical threats. The system can be configured for a variety of CBRN&E scenarios, including handheld wands and swab-type threat detection scenarios requiring short sample times, and scenarios in which longer sampling times are used.

Here we provide an overview of the system design and operation and present results from preliminary testing.

8358-62, Session 9

Coherent x-ray scatter projection imaging using an array of mono-energetic pencil beams

K. Landheer, P. C. Johns, Carleton Univ. (Canada)

Traditional projection X-ray imaging utilizes only the information from the primary photons. Low-angle coherent scatter images can be made simultaneous to the primary images and provide additional information. To speed up acquisition time for coherent scatter projection imaging, we are developing disentangling algorithms for the overlapping scatter patterns generated by multi pencil-beam geometries. We configured a system at the Canadian Light Source synchrotron which utilizes a custom collimator designed to convert a 33.17 keV monoenergetic fan beam from a Laue monochromater into multiple pencil beams by using 3 mm thick tungsten alloy stoppers. The pencil beams then travel through the sample and are absorbed by a tungsten bar. A digital flat panel detector records the superimposed scatter patterns from the beams. The sample is scanned through the beams using an automated step-and-shoot setup. The pixel value of the coherent scatter image is generated by integrating the radial profile (scatter intensity versus scattering angle) over an angular range. The angular range integrated over can be adjusted after the data have been acquired to achieve maximum contrast between any two materials of interest. We developed an MLEM-based iterative method to disentangle the scatter patterns. We are also investigating a least-squares method and using simulated data to compare the accuracy of both methods. Although in the past our work has primarily been applied to medicine, other applications include non-destructive testing and security.

8358-63, Session 9

MOX assay using He-4 scintillation detectors

D. Murer, H. Friederich, R. Chandra, U. Gendotti, G. Davatz, Arktis Radiation Detectors Ltd. (Switzerland)

The established method to assess the Plutonium content in nuclear materials such as Mixed Oxide (MOX) reactor fuel involves using He-3 thermal neutron detectors to perform coincidence counting of fission neutrons. With He-3 becoming obsolete, attention has turned to possible replacement technologies. A novel method to assess the Plutonium content in nuclear materials such as MOX reactor fuel is presented. Unlike conventional techniques, this technique exploits the fact that the Pu-240 fission neutron spectrum extends to higher energies than the non-fission neutron spectrum coming from (alpha,n) neutrons. To detect this spectral difference, He-4 scintillation detectors are used. Monte Carlo modeling and measurement results are presented, along with an analysis of the strengths and weaknesses of the presented technique. This technique can also find applications in other areas such as treaty verification.

8358-64, Session 9

Study of the time structure of the fast neutron background using high-pressured helium-4 scintillators

D. Murer, R. Chandra, U. Gendotti, G. Davatz, H. Friederich, Arktis Radiation Detectors Ltd. (Switzerland)

Neutron detectors are used to interdict illicit trafficking of special nuclear material (SNM) at border crossings and ports of entry. One challenge in such portal monitor applications is to distinguish the neutrons coming from spontaneous fission in SNM from background neutrons causing alarms in commonly deployed neutron detectors.

Such nuisance alarms can occur due to variations in the natural neutron background caused by cosmic ray interactions in vicinity to the detectors, part of which occur in bursts of so-called “ship-effect” neutrons. To increase sensitivity and to lower the nuisance alarm rate in portal monitoring, a good understanding of these variations is necessary in order to distinguish them from the neutrons emitted by a fission source.

Previous work addressed this issue by analyzing the time structure of these bursts but could only provide microsecond time resolution due to the moderator needed for He-3 tubes [1] and concluded that an improved time resolution will result in a much better performance.

In this work, novel fast He-4 scintillators and associated custom electronics are used to study the natural background and devise methods to reject such background exploiting the nanosecond time resolution provided by such a detection system. An assembly of multiple such He-4 detectors is used to study the time structure of the neutron background in various environments such as large surrounding quantities of lead and concrete. These signatures are then compared to the signatures of various neutron sources.

[1] Richard T. Kouzes et al Cosmic-ray-induced ship-effect neutron measurements and implications for cargo scanning at borders, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 587, Issue 1

8358-65, Session 9

Investigations into the polymorphs and hydration products of UO3

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This work focuses on progress in gaining a better understanding of the polymorphic nature of the UO3-water system; one of several important materials associated with the nuclear fuel cycle. The UO3-water system is complex and has not been fully characterized, even though these species are common throughout the fuel cycle. For example, most production schemes for UO3 result in a mixture of up to six or more different polymorphic phases, and small differences in these conditions will affect phase genesis that ultimately results in measureable changes to the end product. Here we summarize our efforts to better characterize the UO3-water system with a variety of optical techniques for the purpose of developing some predictive capability of estimating process history and utility, e.g. for polymorphic phases of unknown origin. Specifically, we have investigated three industrially relevant production pathways of UO3 and discovered a previously unknown low temperature route to β-UO3. Powder x-ray diffraction and optical spectroscopies were utilized in our characterization of the UO3-water system. Pure phases of UO3, hydrolysis products and starting materials were used to establish optical spectroscopic signatures for these compounds. Preliminary aging studies were conducted on the α- and γ- phases of UO3. In addition, development of a 3-D phase field model was used to predict phase genesis under a variety of industrially relevant conditions has been initiated.

8358-66, Session 9

Thermal neutron detection with PMMA nanocomposites containing dysprosium fluoride nanocrystals

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Dy-containing nanocomposites are attractive as sensors of thermal neutron exposure history. We report on the synthesis and loading of a PMMA polymer matrix with DyF3 nanocrystals (NCs) doped with cerium. Optical properties of the nanocomposite as they relate to loading percentage of the NCs have been measured. Also, we will present the contrasting data from HoF3:10%Ce NCs in PMMA, to discuss the differences and the possibilities for differentiation between the small changes in the Ho content due to neutron irradiation. To this end, we have synthesized DyF3:Ce NCs containing varying doping percentages of Ho and examined the differences in their absorption and photoluminescence spectra, as well as in their fluorescence lifetimes. Results of thermal neutron exposure experiments will be described.

8358-67, Session 9

The use of stimulated electron emission (SEE) in homeland security applications

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Certain insulating solids can store a fraction of the absorbed energy when irradiated by ionizing radiation. The stored energy can be released subsequently by heating or optical stimulation and appears in the form of light and/or low-energy electrons. These phenomena-Thermoluminescence (TL), Optically-Stimulated Luminescence (OSL), Thermally-Stimulated Electron Emission (TSEE) and Optically-Stimulated Electron Emission (OSEE)-have been extensively studied in certain materials such as BeO, MgO, CaO, BaSO4, LiF and Al2O3 in connection with underlying solid-state physics and applications for personal radiation dosimetry.

TL and OSL are widely used in current radiation dosimetry systems. However, despite considerable research effort during the early 1970s, SEE was not commonly adopted for dosimetry applications. One of the main reasons is that SEE is a surface phenomenon, while luminescence is a bulk phenomenon, making SEE more susceptible to humidity, absorption of gases, minor physical defects and handling, both before and after irradiation. Nevertheless, it has been recognized that SEE may be useful for homeland security applications in nuclear forensics, where dose accuracy is not the primary performance metric. For detection and tracking of nuclear materials, it is more important to reliably establish the presence or absence of radiation exposure along a pathway than to exactly quantify the radiation dose at any given location.

In this research, we are investigating the use of SEE for nuclear forensic applications. Many common materials, both natural and man-made, exhibit the phenomenon, providing an opportunity to use the environment itself as an in situ radiation detector. We have designed and constructed a unique prototype reader for conducting SEE measurements. Our studies to date have included material samples from a variety of categories, including reference materials, construction and industrial materials, electronic components, personal and household items, and materials from the natural environment. We have demonstrated that the SEE measurements from a variety of materials are quantitatively reproducible and correlated to radiation exposure. Due to the broad applicability of SEE, significant additional studies are warranted to optimize this novel technique for nuclear forensic and other applications.

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8359-01, Session 1

Cyber Security and CyLab: technologies and challenges

P. K. Khosla, Carnegie Mellon Univ. (United States)

No abstract available

8359-02, Session 1

Cyber adversarial behavior analytics

G. Cybenko, Thayer School of Engineering at Dartmouth (United States)

No abstract available

8359-03, Session 2

Novel mechanism of network protection against new generation of cyber attacks

A. Milovanov, L. Bukshpun, R. Pradhan, Physical Optics Corp. (United States)

An intelligent technology has been developed to protect networks against new generation of cyber attacks. This technology integrates a TCP/IP protocol stack protection and attacker deception to eliminate existing TCP/IP protocol stack vulnerabilities and detect currently undetectable, highly distributed, low-frequency attacks such as DDoS, coordinated attacks, botnet, and stealth network reconnaissance. A detected attack is insulated from the network and redirected to a simulated network acting as a decoy. As a result, network security personnel gain sufficient time to defend the network and collect the attack information. This technology can be incorporated into wireless or wired networks that require protection against known and new generation of cyber attacks.

8359-04, Session 2

Inverse game theory: learning the nature of a game through play

G. F. Stocco, Thayer School of Engineering at Dartmouth (United States)

No abstract available

8359-05, Session 2

An analytic approach to cyber adversarial dynamics

P. J. Sweeney, U. S. Air Force (United States); G. Cybenko, Thayer School of Engineering at Dartmouth (United States)

To date, cyber security investment by both the government and commercial sectors have been largely driven by the “myopic best response” of players to the actions of their adversaries and their perception of the adversarial environment. However, current work in applying traditional game theory to cyber operations (often) assumes that “games” exist with prescribed moves, strategies, and payoffs. This paper presents an analytic approach to viewing the more realistic cyber adversarial metagame that we believe is being played. Examples show that understanding the dynamic metagame provides opportunities to exploit an adversary’s anticipated attack strategy.

8359-06, Session 2

Exploiting exploration strategies in repeated normal form security games

J. T. House, G. Cybenko, Thayer School of Engineering at Dartmouth (United States)

No abstract available

8359-07, Session 2

Generating realistic environments for cyber operations development, testing, and training

V. H. Berk, I. Gregorio-de Souza, J. P. Murphy, Dartmouth College (United States)

No abstract available

8359-08, Session 2

Thwarting enviromentally aware malware

D. Bilar, Dartmouth College (United States)

No abstract available

8359-09, Session 2

Automated malware detection using data model LUTs

H. M. Jaenisch, J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We present the successful demonstration of malware versus non-malware discrimination using byte word distributions. We detail a simple method for ingesting the ASCII word sequences from compiled codes and estimate running descriptive statistical features (heptors) on the codes and derive a multivariate polynomial (Data Model) classifier from the first two principal components. We show the results for a small historically significant malware set against 6000+ Windows XP EXE and DLL files. We further demonstrate that the boundary between malware and non-malware is fractal. Derived Data Model equations and instantiated Look Up tables (LUTs) are provided along with performance scores and path forward. Where applicable MathCad type source code and Ruby scripts required to reproduce our work are included.

8359-10, Session 3

Rapid multiple pathogen detection using a portable microfluidic system

U. Demirci, Harvard Medical School (United States)

No abstract available

8359-11, Session 3

Noncontact liquid explosive detection device

P. J. Prado, One Resonance, LLC (United States)

The use of liquid explosives for terrorist attacks is an eminent threat for both civilian and military personnel. An effective method to rapidly screen bottles provides a solution for checkpoints at secured facilities and public events and opens the possibility to lifting the ban to airplane travel with liquids.

Various technologies have been proposed to screen bottles to verify that their content is non-hazardous. All methods proposed this far suffer from critical detection performance weaknesses. For example, Raman and NIR instruments are effective at classifying liquids, but do not operate properly with dark glass bottles. X-ray methods are still to demonstrate that they provide sufficient specificity to reduce their typical large number of false alarms. Trace detection methods fail when the containers are properly cleaned.

Magnetic Resonance (MR) provides a new, robust method to detect liquid explosives, overcoming the weaknesses of approaches tested to date. The method is effective with bottles of any size and with any type of glass, plastic, cardboard and other materials.

One Resonance LLC is introducing a new method that is not relying on the verification of the bottle content, rather on a direct detection of threats, included homemade explosives. Feasibility for the detection modality has been demonstrated with various hazardous liquids.

The MR based scanning modality provides a powerful non-contact method to screen bottles regardless of their shape and opacity.

8359-12, Session 3

Fast analysis of chemical taggants using laser-induced breakdown spectroscopy

J. R. Almirall, Florida International Univ. (United States); A. W. Miziolek, U.S. Army Research Lab. (United States)

A forensic identification tagging system that can be easily applied, detected and analyzed, imparting a unique elemental fingerprint to any object is presented. The taggant is composed of a liquid polymer that has a unique combination of rare elements for each product formulation. The unique elemental combination is produced only once with several billion unique formulations available to users depending only on the presence or absence of the rare elements in the formulation. A fast qualitative and semi-quantitative analysis method was optimized and validated for the liquid and solid forms of the taggant using Laser Induced Breakdown Spectroscopy as the detection system (and confirmed with LA-ICP-MS) . Recovery and persistence studies were also investigated to determine the utility of the system in real-world situations. Analysis was conducted as a blind test on 180 different and unique product formulations as obtained from the manufacturer and in all cases, the correct combination of elements for each product was successfully identified. The SmartWater® Technology polymers can be applied to surfaces without altering the appearance of a surface in order to uniquely identify and track objects when combined with LIBS detection.

8359-13, Session 3

Use of ISR sensors for detection of chemical and biological agents

H. Malik, Northrop Grumman Electronic Systems (United States); C. Parker, Camber Corp. (United States)

Attacks with Chemical or Biological (CB) agents can have significant consequences. However, the rarity of the events results in a low density of detection assets based on perceived requirements. It is advantageous to leverage existing, more widely deployed sensor assets to assist with the detection of CB agents. One technique is to use tactical Intelligence Surveillance and Reconnaissance (ISR) sensors to enhance the capabilities of those CB sensors which are deployed. Some differences in the sensor requirements for the two types of missions are explained, along with ways they could be used to detect, or at least indicate, a possible chemical or biological agent attack. Results from field tests are used to show a few possible approaches. Combined with CB sensors the ISR-CB systems CB detection capabilities were enhanced during the field test. Detection times were reduced by 70%. Lessons learned can be applied to other sensor fusion scenarios, especially those where data from many disparate sensors is available.

8359-14, Session 4

Intersubband lasers diodes from IR to THZ: recent advances and future trends

M. Razeghi, Northwestern Univ. (United States)

No abstract available

8359-15, Session 5

Cost-sensisitive hardware encryption of existing wireless communication networks

B. M. Kaminski, A. R. Wannemacher, J. S. Wells, NuWaves Engineering (United States)

In the defense industry it is becoming necessary in some cases to encrypt an existing unencrypted or weakly encrypted wireless communication link. Factors affecting such a requirement include classification of data that was not previously classified, repurposing a communication link for a new function requiring encryption, or a change in the acceptability of an existing encryption algorithm. In these cases it is usually desirable to insert encryption and decryption capabilities into the communication network without drastically changing the function, structure, or characteristics of the existing network. The easiest way to accomplish this is usually through a software update. However, that is not always possible for various reasons which are explained. This paper discusses the general process by which encryption can be implemented using electronics hardware, and places an emphasis on cost-savings along the way. It addresses the stages of a typical hardware development project, including requirements gathering, algorithm and platform selection, hardware design cycles, regulatory compliance, management of encryption keys, documentation updates, deployment, and personnel training.

8359-16, Session 5

Turboprop aircraft against terrorism: a SWOT analysis of turboprop aircarft in CAS operations

M. Yavuz, A. Akkas, Turkish Air War College (Turkey)

Today, the threat perception is changing. Not only for countries but also

for defence organisations like NATO, new threat perception is pointing terrorism. Many countries' air forces become responsible of fighting against terorism or Counter-Insurgency (COIN) Operations. Different from conventional warfare, alternative weapon or weapon systems are required for such operatioins. In counter-terrorism operations modern fighter jets are used as well as helicopters, subsonic jets, Unmanned Aircraft Systems (UAS), turboprop aircraft, baloons and similar platforms. Succes and efficiency of the use of these platforms can be determined by evaluating the conditions, the threats and the area together. Obviously, each platform has advantages and disadvantages for different cases.

In this research, examples of turboprop aircraft usage against terrorism and with a more general approach, turboprop aircraft for Close Air Support (CAS) missions from all around the world are reviewed. In this effort, a closer look is taken at the countries using turboprop aircraft in CAS missions while observing the fields these aircraft are used in, type of operations, specifications of the aircraft, cost and the maintenance factors. Thus, an idea about the convenience of using these aircraft in such operations can be obtained. A SWOT analysis of turboprop aircraft in CAS operations is performed. This study shows that turboprop aircraft are suitable to be used in counter-terrorism and COIN operations in low threat environment and is cost benefical compared to jets.

8359-17, Session 5

Multirobot terrain coverage and task allocation for autonomous detection of landmines

R. Dasgupta, A. Munoz Melendez, K. R. Guruprasad, Univ. of Nebraska at Omaha (United States)

Multi-robot systems comprising of heterogeneous autonomous vehicles on land, air, water are been increasingly used to assist or replace humans in different hazardous missions. Two crucial aspects in such multi-robot systems is to a) explore an initially unknown region of interest to discover tasks, and, b) allocate and share the discovered tasks between the robots in a coordinated manner using a multi-robot task allocation (MRTA) algorithm. In this paper, we describe results from our research on novel multi-robot terrain coverage and MRTA algorithms within an autonomous landmine detection scenario, done as part of the ONR-funded, COMRADES project. Each robot is equipped with a different type of landmine detection sensor and different sensors, even of the same type, can have different degrees of accuracy. The landmine detection-related operations performed by each robot are abstracted as tasks and multiple robots are required to complete a single task. First, we describe a novel distributed and robust terrain coverage algorithm that employs Voronoi partitions to divide the area of interest among the robots and then uses a single-robot coverage algorithm to explore each partition for potential landmines. Then, we describe MRTA algorithms that use the location information of discovered potential landmines and employ either a greedy strategy, or, an opportunistic strategy to allocate tasks among the robots while attempting to minimize the time (energy) expended by the robots to perform the tasks. We report experimental results of our algorithms using accurately-simulated as well as physical Corobot robots performing a multi-robot, landmine detection operation.

8359-18, Session 5

Strategic military message system oriented to obtain the tactical picture

G. Perez, S. Marrugo, COTECMAR (Colombia)

This paper describes the design of a Strategic Military Message System (SMMS), oriented to obtain the tactical picture, in order to supervise operations. The SMMS, is part of a project that pretend to create a Joint Command and Control System at strategic level. The system design is based, primarily, on the careful selection that was made of the contents of messages, in order to obtain the data necessary for simulation and operations research process at the Command and Control strategy center. The system was designed taking into account low bandwidth transmission media (HF / VHF / UHF). The SMMS security is based on a series of processes, which are guaranteed by mechanisms of public key cryptography, presenting as an advantage that the confidence relation of the system rests strictly on staffs planning the operations. The paper also shows some of the results obtained from the system testing.

8359-19, Session 5

Catastrophe extraction of anomalous events

T. P. Jannson, T. C. Forrester, S. Ro, Physical Optics Corp. (United States)

Intelligence exploitation systems and technologies include such novel data mining techniques as catastrophic extraction of anomalous events by software algorithm based on theory of catastrophes, being mathematical theory of manifolds, formulated by Whitney (U.S. 1955), Thom (France), and Arnold (Russia).

This rather unknown theory allows to reduce a large number of parameters-based-complex physical and non-physical (social, etc), problems to few essential so-called state variables. This paper discusses, for simplicity, mostly co-rank-one catastrophes with only one state variable and arbitrary co-dimension (a number of control variables).

In specifically designed examples illustrating critical physical problems we demonstrate an extraction of discrete (anomalous) events from continuous hyper-surfaces (manifolds). Such hyper-surfaces can be created by on-the-move (OTM) platform's performance-control instruments. Platforms include: avionics (aircraft), ground (vehicle), stage, UAVs, UGVs, and others. In this paper, we propose a strategy of how to extract anomalous events such as specific engine failures, automatically, without supervision of experts. Such indication of warning, a kind of data mining, can be used for prediction of catastrophic, or non-catastrophic failures of DTM platforms of interest for homeland security and homeland defense.

8359-20, Session 5

Resource management tools based on renewable energy sources

T. P. Jannson, T. C. Forrester, Physical Optics Corp. (United States)

Renewable energy sources are important sources of power for unattended: ground, sea, and air sensors, tagging systems and other remote miniature platforms for homeland security and homeland defense. Also, command and control systems and technologies often require renewable energy sources for information assurance (IA) anti-tampering purposes. However, various geophysical and environmental conditions prefer different types of energy harvesting, including: solar, thermal (based on thermal gradient), phase-material-based, acoustic (vibration) energy-based, sky-temperature-based, hydraulic energy based (using ocean waves or ocean currents), wind energy based, and others. Among them, solar energy is usually preferable but then either solar habitat or necessity of night operation can create a need for other renewable energy types.

8359-21, Session 5

Application of the replicator equations to decision-making processes in border security

D. Sicilia, G. Cybenko, Thayer School of Engineering at Dartmouth (United States)

No abstract available

8359-22, Session 5

Nirvana: managing large-scale heterogenous data structures for real-time C3I

D. P. Schissel, General Atomics (United States)

No abstract available

8359-23, Session 6

Situational awareness and informed decision making for law enforcement responders

G. C. Tillery, National Institute of Justice (United States)

No abstract available

8359-24, Session 6

Revolutionary development ¾ of Type 11 GaSb/InAs superlattices for third generation of IR imaging

M. Razeghi, Northwestern Univ. (United States)

No abstract available

8359-25, Session 7

Using VIS/NIR and IR spectral cameras for detecting and separating crime scene details

J. Kuula, I. J. Pellikka, H. Salo, I. Pölönen, Univ. of Jyväskylä (Finland); H. Saari, VTT Technical Research Ctr. of Finland (Finland)

Project group will study how to achieve a faster and a more efficient crime scene investigation process based on VIS/NIR and IR tunable filter spectral cameras in wavelength range 500 - 2500 nm. Currently chemicals are needed for finding evidence of crimes. The spectral camera system is capable of finding the evidence without need for chemicals, and then DNA readability remains. The project will study different kinds of classification algorithms for specified research items, and it will also develop the most suitable algorithms for them. A lot of different light sources are presently used to find blood stains etc. from crime scene. The use of spectral imaging of crime scene in addition to or together with light sources enables to find more details from the scene. One of the advantages of spectral imaging is the possibility to differentiate blood stains belonging to different persons. This way samples can be collected for all blood stains that differ from each other. With light sources blood stains can be found and samples can be collected but it is not possible to know are the samples from one person only or from several different persons.

8359-26, Session 7

Re-identification of persons in multicamera surveillance under varying viewpoints and illumination

H. Bouma, S. Borsboom, R. den Hollander, S. Landsmeer, TNO Defence, Security and Safety (Netherlands); M. Worring, Univ. of Amsterdam (Netherlands)

The capability to track and trace individuals in CCTV cameras is important for surveillance and forensics. However, it is laborious for a camera operator to do this over multiple cameras. Therefore, an automated system is desirable that can assist the operator in his search for specific persons. For automatic person tracking over multiple cameras without overlapping views, the main component is a person-matching algorithm. The task of this algorithm is to find the person images in a large collection that are most similar to a query person image. Images of the same person are ranked as high as possible, preferably first.

Our computationally efficient person-matching method - which is mainly based on multi-dimensional histograms containing color and spatial information - is described in detail in this paper. We compare the performance of our method to several state-of-the-art methods. To evaluate the performance of these algorithms the VIPeR dataset (from ucsc.edu) was used, because it is a publically available benchmark for viewpoint-invariant person reidentification algorithms. This dataset consists of two different recordings for 632 individuals. The data contains a wide variety of view-points, poses, backgrounds and lighting conditions; as seen with surveillance systems in an outdoor situation.

To estimate the performance and allow comparison, two-fold cross validation was used. The results show that our method performs well. The system is able to retrieve approximately 50% of the images correctly within the best 10 matches. This allows a human operator to speed up the tracking process with a factor of 5.

8359-27, Session 7

Picosecond gating of optical and x-ray images with electron pulse dilation

T. Hilsbeck, General Atomics (United States)

No abstract available

8359-28, Session 7

3D vision system for enhanced robotic tele-operation for the homeland security mission

R. Edmondson, Polaris Sensor Technologies, Inc. (United States)

Polaris Sensor Technologies has developed a stereo vision upgrade kit for TALON robot systems comprised of a replacement gripper camera and a replacement mast zoom camera on the robot, and a replacement display in the Operator Control Unit (OCU). Polaris has also recently collaborated with Harris Corporation to integrate the 3D vision system onto a prototype seven degree of freedom haptic arm. In multiple studies done at Fort Leonard Wood, Missouri it has been shown that 3D vision, and 3D vision combined with haptics, provides more intuitive perception of complicated scenery, allowing for improved mission performance and the potential for reduced time on target. This paper discusses the potential benefits of these enhancements to robotic systems used for the domestic homeland security mission.

8359-29, Session 7

LIBS data analysis using a predictor-corrector-based digital signal processor algorithm

S. T. Griffin, A. L. Robinson, A. Sanders, The Univ. of Memphis (United States)

There are many accepted sensor technologies for generating spectra for material classification. Once the spectra is generated, communication bandwidth limitations favor local material classification with its' attendant reduction in data transfer rates and power consumption. Transferring sensor technologies such as Cavity Ring-Down Spectroscopy (CRDS)

and Laser Induced Breakdown Spectroscopy (LIBS) require effective material classifiers. A result of recent efforts has been emphasis on Partial Least Squares - Discriminant Analysis (PLS-DA) and Principle Component Analysis (PCA). Implementation of these via general purpose computers is difficult in small portable sensor configurations. This paper addresses the creation of a low mass, low power, robust hardware spectra classifier for a limited set of predetermined materials in an atmospheric matrix. Crucial to this is the incorporation of PCA or PLS-DA classifiers into a predictor-corrector style implementation. The system configuration guarantees rapid convergence. Software running on multi-core Digital Signal Processor (DSP's), simulates a stream-lined plasma physics model estimator, reducing Analog-to-Digital (ADC) power requirements. This paper presents the results of a predictor-corrector model implemented on a low power multi-core DSP to perform substance classification. This configuration emphasizes the hardware system and software design via a predictor corrector model that simultaneously decreases the sample rate while performing the classification.

8359-30, Session 7

Development of a high-sensitivity UV photocathode using GaN film that works in transmission mode

Y. Ishigami, K. Akiyama, T. Nagata, K. Kato, T. Ihara, K. Nakamura, I. Mizuno, Hamamatsu Photonics K.K. (Japan); T. Matsuo, E. Chino, Sanken Electric Co., Ltd. (Japan); H. Kyushima, Hamamatsu Photonics K.K. (Japan)

We developed a high-sensitivity GaN photocathode that works in transmission mode. It has 40.9 % quantum efficiency at 310 nm wavelength.

Conventional GaN photocathodes, both transmission mode and reflection mode, are made on a sapphire substrate using metalorganic vapor phase epitaxy (MOVPE). In reflection mode, a GaN photocathode has very high quantum efficiency of over 50 %. However, in transmission mode, the quantum efficiency of a GaN photocathode was about 25 % at 240 nm. This decrease in quantum efficiency is caused by the interface between the glass and GaN surfaces. Due to interfacial defects, the conduction band dips down and traps electrons near the glass/GaN interface. The trapped electrons cannot travel across the GaN layer towards the GaN/vacuum interface, and thus cannot be emitted.

We made a potential barrier using an AlGaN layer to avoid interfacial effects. The GaN photoemissive layer was grown on a Si wafer with GaN/(GaN/AlN) multilayer by MOVPE. At the last stage of crystal growth, an AlGaN layer was grown on the GaN photoemissive layer. After bonding to a UV-transparent glass face plate, the Si substrate and subsequent GaN/(GaN/AlN) multilayer were removed by wet etching. The final product had a glass/AlGaN/GaN structure, and we cleaned that surface and activated it using cesium and oxygen carefully in vacuum. We achieved a GaN transmission-mode photocathode with high quantum efficiency.

The high-sensitivity UV photocathode will be used for flame detection, corona discharge observation, and other UV imaging.

8359-31, Session 8

Trends in transportation security

S. F. Hallowell, Transportation Security Lab. (United States)

No abstract available

8359-32, Session 8

Guardian counter-manpad system implementation status

D. Denton, Northrop Grumman Electronic Systems (United States)

No abstract available

8359-33, Session 9

Action vision sensor (AVS): a bio-inspired sensor for detection and localization of action and transient events

J. H. Lin, P. O. Pouliquen, A. G. Andreou, The Johns Hopkins Univ. (United States); C. G. Rizk, The Johns Hopkins Univ. Applied Physics Lab. (United States)

We present a vision sensor for extracting salient information from a scene. Transient events such as the muzzle flash from a firing gun are detected on-chip by analyzing the change in pixel intensity. Our image sensor readout architecture utilizes a novel event based auto-scanning mode where only pixels within a programmable range of photon flux rates are output. This is in contrast to traditional image sensor readout architectures which output the intensity value of every pixel, which is costly in terms of system performance parameters such as speed and power. Our imager can output events at a rate of 12.5 million events per second. In random access read mode, the imager can output full frames up to 5.8 kiloframes per second. As the sensor array size grows, there is negligible impact on output event rate, whereas full frame rate decreases proportionally. Each pixel contains a one bit oversampled analog-to-digital converter together with a decimator, which allows for the quantization of signals up to 26 bits. Furthermore, digital non-uniformity correction of both gain and offset errors is applied at the pixel level prior to readout. We report results from a prototype array fabricated in a standard 90nm CMOS process.

8359-34, Session 9

Archiving image sequences with regard to associated geographical and nongeographical attributes to allow reconnaissance and surveillance tasks to be performed more efficiently

S. T. Bruestle, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Image sequences (e.g. video) gathered by a sensor mounted on an airborne platform (e.g. UAV) are used today to address many different tasks in various fields of application. Sequences are usually taken to gather information of an area for planning and assessing purposes, to witness any changes and to monitor activities within that area. Image sequences are usually stored as they are taken. In order to perform the above tasks in a post processing step properly, it is necessary to find relevant sequences or subsequences in the huge amount of stored data efficiently. Therefore it is mandatory to store the sequences in a way to enable retrieving any relevant frame or subsequence with respect to geographical attributes such as e.g. the position of the footprint center and/or nongeographical attributes such as the date and time gathered or the spectral band of gathered sequence. We have developed a method to store each frame of an image sequence into a spatial relational database in a way that addresses this issue. We further have developed an interface to that database that allows us to retrieve frames and subsequences both employing task specific clients and existing exploitation software systems such as Fraunhofer IOSB's ABUL exploitation station.

8359-35, Session 9

High-performance, event-driven, low cost, and SWaP imaging sensor for hostile fire detection, homeland protection, and border security

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No abstract available

8359-36, Session 9

3D scanning and imaging for quick documentation of crime and accident scenes

M. Scaioni, Politecnico di Milano (Italy); C. Cattaneo, Univ. degli Studi di Milano (Italy); R. Sala, A. Giussani, L. Barazzetti, F. Roncoroni, Politecnico di Milano (Italy); P. Poppa, D. Gibelli, Univ. degli Studi di Milano (Italy)

Fast documentation of complex scenes where accidents or crimes occurred is fundamental not to lose information for post-event analyses.

Today 3D laser scanning technology offers instruments capable of achieving this task. ToF scanners, phase-shift scanners and close range scanners cover all ranges involved in possible scenarios with adequate resolution and precision. The chance to register alla 3D data into a common reference system allows to integrate and overlap scans gathered from different stand-points and diverse instruments. In addition, the integration of registered images adds up visual information on details that cannot be depicted in 3D point clouds. Thanks to photogrammetric techniques, images can be used to extract metric information as well.

Visualization of results through an ease-to-use 3D environment is another import issue to offer useful data to investigators. Here some commercial 3D and photogrammetric software packages have been used to store and query the final dataset.

Three different experiences of crime scene documentation are proposed. These come out from simulated scenarios involving bone dispersion in open areas, and animal body explosion to simulate human body dispersion after terrorist attack or chemical accident.

The aim of this research has been to setup recomendation and best practices to apply these surveying methodology in actual scenarios.

8359-37, Session 9

Large area, clear, transparent superhydrophobic coatings

J. T. Simpson, S. R. Hunter, Oak Ridge National Lab. (United States)

The ability to coat a surface with a well bonded, clear, transparent, high quality superhydrophobic coating would have many practical advantages, not the least of which would be to make a coated surface clean and dry, even in wet conditions. This paper describes research done at oak Ridge National Laboratory (ORNL) that has successfully created such a coating. We will discuss why it was so difficult to make such coatings, how others have attempted to make such coatings, and how we are overcoming these problems.

We will discuss how we coated large pieces of glass and plexiglass sheets, optical lenses and filters, and electronic components. We will also give test results of these coated pieces showing contact angle of excess of 175 degrees and roll-off angles of less than 1 degree. We will also give transmission and reflectance data showing that these coatings have good optical quality and are anti-reflective in nature. Finally we will show some standard “tape” test results indicating that these coatings are much more durable than other transparent superhydrophobic coatings.

8359-38, Session 10

Non-lethal weapons: technologies and challenges

D. B. Law, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

8359-39, Session 11

Characterization the influence of micro and terahertz waves on human in security systems

M. Zyczkowski, N. Palka, M. Karol, Military Univ. of Technology (Poland); B. Uzieblo-Zyczkowska, Military Institute of Medicine (Poland)

The nature of recent conflicts, terrorist attacks and military conflicts as well as the necessity to protect bases, convoys and patrols gave serious impact to the development of more effective security systems. Widely-used so far concepts of perimeter protection with zone sensors will be replaced in the near future with multi-sensor systems. This kind of systems can utilize as millimeter-wave radars detecting radiation reflected from target and from recent the terahertz system detecting if man is not hiding something under clothing. Ranges of detection, recognition and identification for all targets depends on the parameters of the sensors used and the observed scene itself. In this paper we present the results of research into the impact of radiation on human a such system. The main area of concern was the microwave and terahertz radiation, in terms of power devices and lighting time of man.

8359-40, Session 11

Direct electromagnetic stopper: an innovative nonlethal weapon working in time domain

M. D’Urso, A. Buonanno, M. G. Labate, SELEX Sistemi Integrati S.p.A. (Italy); D. Pavone, Consorzio Nazionale di Ricerca per le Tecnologie Optoelettroniche dell’InP (Italy)

The capability of the electromagnetic waves to interact with electric parts of vehicles or electronic devices can be used as non-lethal weapons. Such kind of systems can be efficiently used for defence and military applications, in particular for properly talking non-cooperative vehicles. In particular, it has been demonstrated that bursts of pulsed electromagnetic waves with peak powers on the order of many Mega-Watts, repetition period on the order of tens of microseconds and frequency in the range of 200 -1500 MHz can modify the behaviour and/or damage the electronic staff of non-cooperative vehicles at a distance on the order of a few tens of meters. In this contribution, we show that a modular approach to design a Direct Electromagnetic Stopper can be introduced and exploited for derive a new architectural solution which properly combining our expertise in designing advanced wideband radiating elements, efficient feeding network and the capability to manage very high power based systems. The overall architecture is composed by a clustered time-domain based arrays, properly feeding. In particular, the radiating cluster is mainly composed by TEM horns antennas that allow to obtain very large gain, wide bandwidth and obviously great output power. The pulse forming network is then realized by using Blumlein transmission lines, which allow to achieve high-voltage pulses with short rise and fall times. Preliminary results on the overall system performances will be shown during the conference

8359-41, Session 11

Detection and localization of R/C electronic devices using Hurst parameter

V. Thotla, M. T. A. Ghasr, M. Zawodniok, S. Jagannathan, Missouri Univ. of Science and Technology (United States); S. Agarwal, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Traditional approach to locating items relies on “tagging” with a special tracking device, for example GPS receiver. This process of tagging is often impractical and costly since additional device may be necessary. Conversely, in many applications it is desired to track electronic devices, which already emit unintentional, passive radio frequency (RF) signals. The emission can be used to detect and locate such electronic devices. Existing schemes often relay on a priori knowledge of the parameters of RF emission, e.g. frequency profile, and work reliably only on short distances. In contrast, the proposed methodology aims at detecting the inherent self-similarity of the emitted RF signal by using Hurst parameter, which (1) allows detection of unknown (not-pre-profiled) devices, (2) extends the detection range over signal strength (peak-detection) methods, and (3) increases probability of detection over the traditional approaches. Moreover, the distance to the device is estimated based on the Hurst parameter and passive RF signal measurements such that the detected device can be located. Theoretical and experimental studies demonstrate improved performance of the proposed methodology over existing ones, for instance the basic received signal strength (RSS) indicator scheme. The proposed approach increases the detection range by 70%, the probability of detection by 60%, and improves the range estimation and localization accuracy by 70%.

8359-42, Session 12

Passive electro-optical projectiles tracker

I. P. Agurok, W. Falicoff, R. Alvarez, W. Shatford, Light Prescriptions Innovators, LLC (United States)

Surveillance, detection, and tracking of multiple high-speed objects, particularly bullets, RPGs, and artillery shells, can help military forces immediately locate sources of enemy fire and trigger countermeasures. The traditional techniques for detection and tracing of fast moving objects are different kinds of radar but, unfortunately, traditional radar has inherently low resolution for such small objects. Fast moving projectiles are aerodynamically heated up to several hundred degree Kelvin temperatures depending on the speed of a projectile. Thereby, such projectiles radiate in the Mid-Infrared (MWIR) region, where electro-optical resolution is far superior, even to microwave radars. A new passive electro-optical tracker (or PET) uses a two-band IR intensity ratio to obtain a time-varying speed estimate from their time-varying temperatures. Based on an array of time-varying speed data and an array of azimuth/elevation angles, PET can determines the 3D projectile trajectory and back track it to the source of fire. Various methods are given to determine the vector and range of a projectile, both for clear and for nonhomogeneous atmospheric conditions. One approach uses the relative intensity of the image of the projectile on the pixels of a CCD camera to determine the azimuthal angle of trajectory with respect to the ground, and its range. A second uses a least-squares optimization technique over multiple frames based on a triangular representation of the smeared image to yield a real-time trajectory estimate. PET's estimated range accuracy is 0.2 m and the azimuth of the trajectory can be estimated within 0.2°.

8359-43, Session 12

Real-time vehicle noise cancellation techniques for gunshot acoustics

A. L. Ramos, Hogskolen i Buskerud (Norway); S. Holm, Univ. of Oslo (Norway); S. Gudvangen, Hogskolen i Buskerud (Norway); R. Otterlei, PosiCom AS (Norway)

Acoustical sniper positioning systems rely on the detection and direction-of-arrival (DOA) estimation of the shockwave and the muzzle blast in order to provide an estimate of a potential sniper's location. Field tests have shown that detecting and estimating the DOA of the muzzle blast is a rather difficult task in the presence of background noise sources, e.g., vehicle noise, especially in long range detection and absorbing terrains. In our previous work presented in the 2011 edition of this conference we highlight the importance of improving the SNR of the gunshot signals prior to the detection and recognition stages aiming at lowering the false alarm and miss-detection rates and, thereby, increasing the system's reliability.

This paper reports on real-time noise cancellation techniques, like Spectral Subtraction and Adaptive Filtering, applied to gunshot signals. In practice, relatively long periods without signal occur and can be used to estimate the noise spectrum as required in the spectral subtraction technique. Our model assumes the background noise as being short-time stationary and uncorrelated to the impulsive gunshot signals. Generally, gunshot signals have a spiky autocorrelation while typical vehicle noise is periodic and exhibits a wider autocorrelation. Regarding adaptive filtering, the NLMS (Normalized Least-Mean-Squares) algorithm seems particularly well suited owing to its ability to distinguish between signals with narrow and wide autocorrelation. Its inherent normalized step-size is also an advantage that copes very well with the transient nature of the gunshot signals. The results presented in this work are supported with extensive simulations based on real data.

8359-44, Session 12

Small arms mini-fire control system: projectile tracker sensor

S. Rajic, Oak Ridge National Lab. (United States)

We discuss our development of an optically based projectile tracking approach. The realization of this technology would substantially increase precision fire lethality by improving long range shot placement. We demonstrate the feasibility of using the rotation of the projectile as the periodic source for a synchronous detection based tracking approach. The projectile itself is completely passive in this concept and thus will contain no emitter, batteries, or electronics of any kind. This type of approach can provide covert projectile precision location information even in daylight conditions. This approach accounts for all external ballistic uncertainty for shots at ranges often more than 1 mile. Even at these extreme ranges round location can be known to better than 0.1 MOA.

8359-45, Session 13

Small arms mini-fire control system: fiber optic barrel deflection sensor

S. Rajic, Oak Ridge National Lab. (United States)

Traditionally the methods to increase firearms accuracy, particularly at distance, have concentrated on barrel isolation and substantial barrel wall thickening to gain rigidity. This barrel stiffening technique did not completely eliminate barrel movement but the problem was significantly reduced to allow a noticeable accuracy enhancement. This process, although highly successful, came at a very high weight penalty. Obviously the goal would be to lighten the barrel (firearm), yet achieve even greater accuracy. Thus, if lightweight barrels could ultimately be compensated for both their static and dynamic mechanical perturbations, the result would be very accurate, yet significantly lighter weight, weapons. We discuss our most recent developments for a barrel reference sensor system that is designed to accomplish this ambitious goal. Our optical fiber-based sensor monitors the barrel muzzle position and autonomously compensates for any induced perturbations. The reticle is electronically adjusted in position to compensate for the induced barrel deviation in real time.

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8360-31, Poster Session

Part-template matching-based target detection and identification in UAV videos

H. Kim, J. Im, T. Kim, Chung-Ang Univ. (Korea, Republic of); J. Bae, S. Lee, Hanwha Corp. (Korea, Republic of); J. Paik, Chung-Ang Univ. (Korea, Republic of)

Recognizing objects in aerial images has been a challenging problem due to various types of image distortion factors, such as motion of a sensing device, weather variation, scale changes, and continuously changing viewpoint. For accurate, robust recognition of objects in UAV videos, we present a novel object detection and identification algorithm using part-template matching and supervised learning. Among various targets of UAV surveillance, the propose target recognition algorithm focuses on the human object. We first build the part-based human data structure by dividing the whole body into the upper half including head and shoulder and lower half of the rest of the body as shown in Figure 1. We compare the detected body region with a set of pre-generated templates arranged in the hierarchical manner as shown in Figure 2.

The difference between the detected human region and a template is expressed in the sum of absolute difference (SAD) as Eq.(1).

The proposed algorithm was tested and evaluated using parking lot image sequences. Humans are recognized by using the matching ratio between the inpute human region and the corresponding templates as shown in Figure 3.In this paper, we present a novel human recognition algorithm using part-template matching and supervised learning for UAV surveillance. The proposed algorithm can separate humans and other objects such as cars and buildings.

8360-32, Poster Session

Polarimetric imaging for ISR

D. B. Chenault, J. L. Pezzaniti, J. Hanks, Polaris Sensor Technologies, Inc. (United States)

Polarimetric imaging systems have opened up new areas for exploitation of natural and target phenomena for defense and homeland security applications by providing additional information to conventional imaging systems. We report on the development of several sensors that are relatively compact and portable that combines imaging with polarization sensitivity in the short wave IR (SWIR), mid wave infrared (MWIR), and long wave infrared (LWIR). These sensors use a variety of multiplexing techniques that enable fast acquisition of spatial and polarimetric data in a part of the spectrum that has heretofore had relatively little imaging data collected in the polarimetric domain. Using these sensors, we have collected data on a variety of defense and homeland security applications with aspects similar to that for airborne sensors. The applications that show promise include port and harbor security, detection of objects on the water with otherwise difficult to sense signatures, compacted soils, and others. We describe the sensors, data collection activities, and results with these sensors.

8360-01, Session 1

Foveated imager providing reduced time-to-threat detection for micro unmanned aerial system

R. M. Bates, K. S. Kubala, A. D. Greengard, FiveFocal LLC (United States)

There is a strong need for improved panoramic imaging and situational awareness for small unmanned aerial systems (UAS). Defense, security, and border patrol systems demand greater panoramic field coverage for threat detection with the ability to zoom into potential threats for identification. Although 360 degree situation awareness systems exist today, the two traditional solutions are limited in capability; gimbaled systems have unacceptable size, weight, power, cost, and limited acquisition time at low altitudes, while fisheye imagers are fundamentally resolution limited. The presented system addresses these weaknesses through a new architecture that delivers a high performance, compact system with constant 360 degree monitoring for threat detection and a 10x zoom capability for threat identification.

The system utilizes a compact catadioptric architecture that relies on miniature camera technology and components where both the wide and zoom channels are imaged onto the same sensor, resulting in a system with a size of 81cm3, a weight of 42g,and power of less than 2W. The size, weight and power allow its use on man portable UAS and UGV platforms, while the system is designed to allow aerial dismount detection in the wide field of view channel with dismount identification in the zoom channel at the same altitude. The paper will present the architecture design trades including native sensor resolution and object space resolution in light of the targeted UAS ConOps. It will describe a 3x improvement in target identification time and demonstrate feasibility with a prototype imager.

8360-02, Session 1

Condor TAC: EO/IR tactical aerial reconnaissance photography system

V. Petrushevsky, D. Tsur, Elbit Systems Electro-Optics El-Op Ltd. (Israel)

Based on the experience gained with the Condor2 long-range oblique photography (LOROP) camera, ELOP is expanding its airborne reconnaissance product line with the Condor TAC tactical photography system. The latter was designed for overflight imaging of extended areas from a fighter or special mission aircraft, at day and night. The Condor TAC is mounted in an aerodynamically shaped pod and can operate in wide envelope of flight altitude and speed. Besides the camera, the pod contains mission management and image processing computer, solid state recorder, wide-band data link for real-time imagery transmission, and two environmental control units. Complex multi-segment optical windows were successfully developed for the system.

The camera system design is modular and highly flexible. Two independent imaging payload modules are mounted inside a gimbal system. Each of the modules is equipped with a strap-down IMU, and may carry a cluster of cameras or a single large camera with gross weight up to 35 kg. The payload modules are interchangeable, with an identical interface to the gimbal. The modularity and open architecture of the system facilitate its adaptation to various operational requirements, as well as allow easy and relatively non-expensive upgrades and configuration changes.

In the current configuration, both EO and IR payload modules are equipped with a combination of longer focal length cameras for bi-directional panoramic scan at medium and high flight altitudes, and shorter focal length cameras for fixed wide angle coverage at low altitudes. All the camera types are equipped with standard format, off-the-shelf area detector arrays. Precise motion compensation is achieved by flexible-pivot back-scan mirrors.

8360-03, Session 1

Airborne infrared hyperspectral imager for intelligence, surveillance, and reconnaissance applications

J. Gagnon, Telops (Canada); E. Puckrin, C. S. Turcotte, Defence Research and Development Canada, Valcartier (Canada); V. Farley, Telops (Canada); J. Bastedo, PV Labs (Canada); M. Chamberland, Telops (Canada)

Persistent surveillance and collection of airborne intelligence, surveillance and reconnaissance information is critical in today's warfare against terrorism. High resolution imagery in visible and infrared bands provides valuable detection capabilities based on target shapes and temperatures. However, the spectral resolution provided by a hyperspectral imager adds a spectral dimension to the measurements, leading to additional tools for detection and identification of targets, based on their spectral signature.

The Telops Hyper-Cam sensor is an imaging spectrometer that enables the spatial and spectral analysis of targets using a single sensor. It is based on the Fourier-transform technology yielding high spectral resolution and enabling high accuracy radiometric calibration. It provides datacubes of up to 320x256 pixels at spectral resolutions as fine as 0.25 cm-1. The LWIR version covers the 8 to 11.8 µm spectral range.

The Hyper-Cam has been recently used for the first time in two compact airborne platforms: a gyrostabilized gimbal and a belly-mounted gyrostabilized mount. Both platforms are described in this paper, and successful results of high-altitude detection and identification of ammonium sulphate are presented.

8360-04, Session 1

UAV-based multispectral environmental monitoring

T. Arnold, M. DeBiasio, R. Leitner, Carinthian Tech Research AG (Austria)

This paper describes an airborne multi-spectral imaging system which is able to simultaneously capture three visible (400-670nm at 50% FWHM) and two near infrared channels (670-1000nm at 50% FWHM). The first prototype was integrated in a Schiebel CAMCOPTER® S-100 VTOL (Vertical Take-Off and Landing) UAV (Unmanned Aerial Vehicle) for initial test flights in spring 2010. The UAV was flown over land containing various types of vegetation. A miniaturized version of the initial multi-spectral imaging system was developed in 2011 to fit into a more compact UAV. The imaging system captured five bands with a minimal spatial resolution of approx. 10mm x 10mm (depending on altitude). Results show that the system is able to resist the high vibration level during flight. After image registration the acquired images are stitched together for land cover mapping and flight path validation. Moreover the system is able to classify different types of vegetation and soil. Future work will include the use of spectral imaging techniques to identify spectral features that are related to water stress, nutrient deficiency and pest infestation. Once these bands have been identified, narrowband filters will be incorporated into the airborne system.

8360-12, Session 1

Fast, compact, computer-free holographic adaptive optics

G. P. Andersen, F. Ghebremichael, HUA Inc. (United States); R. Gaddipati, P. Gaddipati, Centum Engineering (United States)

We have constructed a closed-loop adaptive optics system that operates at 100kHz without the need for a computer. The system uses a multiplexed hologram which is essentially pre-programmed with the response functions of each actuator in a given deformable mirror. An input beam incident on this hologram reconstructs a pair of focused beams - one for each actuator. The power ratio of each pair is directly related to the absolute phase of the wavefront for a particular actuator, so a simple feedback circuit between a fast photodetector array and the deformable mirror can provide fast, computer-free closed-loop correction.

We present results from a working holographic adaptive laser optics system (HALOS) incorporating a 32-actuator MEMS-based deformable mirror and an off-the-shelf, photon counting avalanche photodiode array. A simple digital circuit has been constructed to provide autonomous control and the entire system is no larger than a shoebox. Our results demonstrate that this device is largely insensitive to obscuration and in principle can run as fast with one actuator as with one million. We will further show how HALOS can be used in image correction, laser beam projection as well as phased-array beam combination.

8360-05, Session 2

Characterization and discrimination of large caliber gun blast and flash signatures

B. J. Steward, K. C. Gross, G. P. Perram, Air Force Institute of Technology (United States)

Two hundred and one firings of three 152 mm howitzer munitions were observed to characterize firing signatures of a large caliber gun. Muzzle blast expansion was observed with high-speed (1600 Hz) optical imagery. The trajectory of the blast front was well approximated by a modified point-blast model described by constant rate of energy deposition. Visible and near-infrared (450 - 850 nm) spectra of secondary combustion were acquired at ~0.75 nm spectral resolution and depict strong contaminant emissions including Li, Na, K, Cu, and Ca. The O2 (X→b) absorption band is evident in the blue wing of the potassium D lines and was used for monocular passive ranging accurate to within 4 - 9%. Time-resolved midwave infrared (1800 - 6000 cm-1) spectra were collected at 100 Hz and 32 cm-1 resolution. A low dimensional radiative transfer model was used to characterize plume emissions in terms of area, temperature, soot emissivity, and species concentrations. Combustion emissions have ~100 ms duration, 1200 - 1600 K temperature, and are dominated by H2O and CO2. Non-combusting plume emissions last ~20 ms, are 850 - 1050 K, and show significant continuum (emissivity ~0.36) and CO structure. Munitions were discriminated with 92 - 96% classification accuracy using only 1 - 3 firing signature features.

8360-06, Session 2

Fiber optic snapshot hyperspectral imager

D. J. Mansur, J. Rentz Dupuis, R. Vaillancourt, OPTRA, Inc. (United States)

OPTRA is developing a snapshot hyperspectral imager (HSI) employing a fiber optic bundle and dispersive spectrometer. The fiber optic bundle converts a broadband spatial image to an array of fiber columns which serve as multiple entrance slits to a prism spectrometer. The dispersed spatially resolved spectra are then sampled by a two-dimensional focal plane array (FPA) at a greater than 30 Hz update rate, thereby qualifying the system as snapshot. Unlike snapshot HSI systems based on computed tomography or coded apertures, our approach requires only the remapping of the FPA frame into hyperspectral cubes rather than a complex reconstruction. Our system has high radiometric efficiency and throughput supporting sufficient signal to noise for hyperspectral imaging measurements made over very short integration times (< 33 ms). The overall approach is compact, low cost, and contains no moving parts, making it ideal for unmanned airborne surveillance. In this paper we present a preliminary design for the fiber optic snapshot HSI system.

8360-07, Session 2

Lidar flecks: modeling the influence of canopy type on tactical foliage penetration by airborne, active sensor platforms

R. D. Massaro, J. Zinnert, J. Anderson, Army Geospatial Ctr. (United States)

Our research focuses on the Army's need for improved detection and characterization of targets beneath the forest canopy. The advent of full-waveform LiDAR detectors has enhanced the ability to penetrate overstory canopies to image the understory and forest floor. However, species composition of canopy and subcanopy woody vegetation affects canopy architecture and thus the ability to fully image below vegetative features for understory terrain characterization. By investigating the integration of specific canopy characteristics with emerging remote data collection methods, foliage penetration-based target detection can be greatly improved. The objective of our research was to empirically model the effects of different vegetation canopy enclosures on the success of foliage penetration (FOPEN) from LiDAR airborne sensors. By quantifying various canopy types we modeled canopy features including leaf structure and type, leaf area indices (LAI), leaf distribution and orientation, and species composition to improve our predictions of the best possible airborne observation parameters (required sensing modalities and geometries) for foliage penetration.

LiDAR range and point cloud data were acquired during the growing season using two linear-mode sensors: NGA's JAUDIT, which was built specifically to acquire data for FOPEN, and the Riegl Q680i. Canopy penetration to the forest floor was verified in some locations by low light level imaging techniques. Validation of both sensors' performance has been accomplished at various sites representing single and multi-layered vegetative canopies using a variety of target materials. Tests were conducted in coordination with extensive ground measurements in four distinct ecological communities varying in species composition and canopy architecture: Guana Tolomato Matanzas National Estuarine Research Reserve, St. Augustine, Florida (maritime forest with broadleaf evergreens); Virginia Commonwealth University Rice Center (loblolly pine monoculture); Virginia Coast Reserve Hog Island (evergreen broadleaf shrub monoculture); and Dahlgren, Virginia (deciduous hardwood forest). At each site measurements of canopy architecture, species composition and light penetration were taken concurrent with LiDAR airborne missions. The canopy type directly affected absorption of incoming laser pulses and percentage of light reaching the ground below. The four communities displayed various levels of complexity in structural arrangement of leaves, with the highest LAI occurring in evergreen broadleaf shrub monoculture.

Principal components analysis was used to correlate the area density of confirmed LiDAR ground returns with collected canopy characteristics and the known sensor geometries. We are currently developing empirical models from this statistical analysis for LiDAR FOPEN in each forest community. Variations in canopy structure and species composition profoundly influenced light patterns at the forest floor. Sunfleck patterns (brief periods of direct light) are analogous to potential "LiDAR flecks" that reach the forest floor, creating a heterogeneous environment in the understory. The spatio-temporal variation in light was a function of both canopy composition and LAI. Size and spatial distribution of LiDAR flecks varied in the different communities, with best penetration in the maritime forest. The shrub monoculture attenuated the most light, resulting in sunflecks of short duration and low intensity. However, even with dense vegetation and low light penetration, we were still able to discern terrain features below the canopy. Based on our field work and analysis of the LiDAR point clouds, our research is expounding on knowledge of canopy-specific characteristics to influence flight geometries for prediction of the most efficient foliage penetrating orientation and heading of an airborne sensor. Our hope is that this research will ultimately enhance airborne sensor flight plans by limiting mission sorties and allow more effective use of time and sensors over foliage-covered terrain.

8360-08, Session 2

Image stabilization for moving platform surveillance

Z. A. Ansari, Instruments Research & Development Establishment (India) and Indian Institute of Technology Kharagpur (India); S. Sengupta, Indian Institute of Technology Kharagpur (India); A. K. Singh, A. Kumar, Instruments Research & Development Establishment (India)

Line of sight jitter degrades the image/real time video quality of a high performance sighting system, resulting in reduced detection/recognition/identification ranges. Line of sight jitter results from residual dynamics on the sighting system from the host platform. A scheme for fine image/video stabilization, in presence of high magnitude line of sight jitter, has been presented in this paper. The proposed scheme is a combination of conventional gyro stabilization of payload line of sight (i.e Mechanical Image Stabilization-MIS) and Digital Image Stabilization (DIS). Gyro stabilization technique is used to minimize the computation requirement of DIS technique. The proposed technique has been implemented and evaluated using standard hardware (SMT8039) available in our laboratory. Inclusion of DIS algorithms has given an additional disturbance isolation of at least 10 dB in our experiments, while image smoothness index also improved by a factor of four or more. The proposed method also indicated that higher image smoothness and disturbance isolation are possible at comparatively higher frequencies (limited by computation capability of the computing platform).

For experimental verification of the proposed scheme, a video camera was mounted in the set of stabilized gimbals. The assembly was then given angular oscillation corresponding to the expected disturbance. Gimbal isolates the camera from the induced disturbances (coarse stabilization). DIS is then applied on the video obtained at this stage. After evaluation of a number of algorithms for DIS, Adaptive Rood Pattern (ARP) based block matching has been selected for local motion estimation due to its simplicity and fast computation. Similarly, for estimation of global motion vector, moving average filter has been found to give best results. Intentional motion is then isolated from the computed jitter on video and compensation is done for jittery motion only.

DIS implementation has been implemented for real-time evaluation. Due to limitation of size of internal memory of DM642, only reference and current (search window) blocks have been copied into the internal memory before motion estimation. Use of memcpy instruction instead of for loop to read Y-data for motion estimation results in more efficient implementation. Data transfer via DMA controller reduces memory I/O stalls substantially. Use of pointers for current and reference images results in faster update of reference frame for motion estimation of next acquired frame. Implementation of motion compensation algorithm in video frames in FPGA using line buffers lowers the computational load of DSP.

After successful development of proposed scheme, performance of integrated system was evaluated.

Gimballed camera was mounted on a motion simulator and known disturbances were given. Pixel movement in acquired video will depend upon angular disturbance level and the Field-of-View (FOV) of the camera. Visual inspection of the video provides qualitative estimation of improvement of video quality in presence of disturbance, since it is not possible to know the exact intentional and unintentional motions.

8360-09, Session 2

Enhanced intelligence trough optimized TCPED concepts for airborne ISR

M. Spitzer, E. Kappes, D. Böker, IABG mbH (Germany)

Current multinational operations show an increased demand for high quality actionable intelligence for different operational levels and users. In order to achieve sufficient availability, quality and reliability of information, various ISR assets are orchestrated within operational theatres.

Especially airborne Intelligence, Surveillance and Reconnaissance (ISR) assets provide - due to their endurance, non-intrusiveness, robustness, wide spectrum of sensors and flexibility to mission changes - significant intelligence coverage of areas of interest.

An efficient and balanced utilization of airborne ISR assets calls for advanced concepts for the entire ISR process framework including the Tasking, Collection, Processing, Exploitation and Dissemination (TCPED).

The enhanced TCPED Concept presented here includes different interoperability levels of ISR assets and organizations as well as shared planning and operation of ISR assets based on consistent situational awareness. Another focus will be the comprehensive use of ISR products for intelligence fusion and consistent evaluation criteria for "intelligence quality" with respect to operational needs.

Beyond this, the employment of current visualization concepts, shared information bases and information customers' profiles, as well as an adequate combination of ISR sensors with different information age and dynamic (online) re-tasking process elements provides the optimization of interlinked TCPED processes towards higher process robustness, shorter process duration, more flexibility between ISR missions and, finally, adequate "entry points" for information requirements by operational users and commands. In addition, relevant Trade-offs of distributed and dynamic TCPED processes are examined and future trends are depicted.

8360-10, Session 3

Rugged GPUs in airborne ISR applications

D. Franklin, GE Intelligent Platforms (United States)

In this paper, we will discuss the impact of Nvidia GPUs and CUDA on rugged ISR applications. Our focus will be on realtime remote sensing applications deployed onboard aerial platforms. We present 4 case studies:

(1) Wide-area EO/IR surveillance, where arrays of imagers are fused into gigapixel-sized mosaics. CUDA is used to align & georeference the mosaic, and perform automatic target recognition & tracking on vehicles and humans across the field of view.

(2) Hyperspectral imaging, where CUDA performs material analysis and classification on high-bandwidth hyperspectral sensors, applicable to a wide range of applications.

(3) SAR/GMTI, where backprojection and STAP algorithms (covariance estimation / cholesky factorization) are parallelized with CUDA.

(4) GSM signal intelligence, where CUDA is used to break A5/1 GSM cellular encryption. An ADC front-end intercepts the voice & SMS traffic and the GPU recovers the A5/1 key for decryption using reverse hash tables.

We will also discuss the rugged systems architecture used to deploy these GPGPU applications. Live demonstrations will be exhibited at booth 1933.

8360-11, Session 3

Shape-based topologies for real-time onboard image generation

A. Bright, S. M. Cruz-Rivera, O. E. Kia, ITT Corp. Geospatial Systems (United States)

The field steerable mirror (FSM) Infrared camera system used in Persistent Surveillance Systems provides wide area coverage using smaller number of cameras. The mirror locations float in a-priori known manner through the field of view and is supposed to be stitched together using image features. This is because the platform motion between mirror positions makes it difficult to exploit a-prior knowledge of the mirror positions. The mosaic generation mechanism developed at ITT utilizes a calibration step which uses elementary shapes that are joined continuously to create complex topologies that capture platform movement. This shape topology process can be extended to other platforms and systems. This paper presents the process by which the meta-data is used in the calibration step that will ultimately allow for real-time Infrared image mosaic generation. By using the geographic coordinates, found in the image meta-data, we are able to estimate the amount of overlap between any two images to be stitched, preventing the need for unnecessary and expensive image feature extraction and matching. This is achieved by using a polygon clipping approach to determine the vertex coordinates of the captured images in order to estimate overlap and disconnection in the field of view.

8360-12, Session 3

Saliency region selection in large aerial imagery using multiscale SLIC segmentation

S. Sahli, Y. Sheng, Univ. Laval (Canada); D. A. Lavigne, Defence Research and Development Canada, Valcartier (Canada)

Advents in new sensing hardwares like GigE-cameras and fast growing data transmission capability create an imbalance between the amount of large scale aerial imagery and the means at disposal for treating them. Selection of saliency regions can reduce significantly the prospecting time and computation cost for the detection of objects in large scale aerial imagery. We propose a new approach using multiscale Simple Linear Iterative Clustering (SLIC) technique to compute the saliency regions. The SLIC is fast to create compact and uniform superpixels, based on the distances in both color and geometric spaces. When a salient structure of the object is over-segmented by the SLIC, a number of superpixels will follow the edges in the structure and therefore acquires irregular shapes. Thus, the superpixels deformation betrays presence of salient structures. We quantify the non-compactness of the superpixels as a salience measure, which is computed using the distance transform and the shape factor. To treat objects or object details of various sizes in an image, or the multiscale images, we compute the SLIC segmentations and the salient measures at multiple scales with a set of predetermined sizes of the superpixels. The final saliency map is a sum of the salience measures obtained at multiple scales. The proposed approach is fast, requires no input of user-defined parameter, produces well defined salient regions at full resolution and adapted to multi-scale image processing.

8360-13, Session 3

Context switching system and architecture for intelligence, surveillance, and reconnaissance (ISR)

P. C. Hershey, C. J. Graham, L. A. Ledda, Raytheon Co. (United States)

With the increasing utilization and dependence on ISR information, operators and imagery analysts monitoring intelligence feeds seek a capability to reduce the processing overload in transformation of ISR data to actionable information. The objective they seek is improvement in time critical targeting (TCT) and response time for mission events. Existing techniques addressing this problem are inflexible and lack a dynamic environment in which to adapt to changing mission events. This paper presents a novel approach to ISR information collection, processing and response, called the ISR Context Switching System (ISR-CSS). ISR-CSS enables ground, sea, and airborne sensors to perform preliminary analysis and processing of data automatically at the platform before transferring actionable information back to ground-base operators and intelligence analysts. The on-platform processing includes a catalogue of filtering algorithms concatenated with associated compression algorithms that are automatically selected based on dynamic events occurring during the mission. The filtering algorithms use tunable parameters and sensitivities based on the original mission plan along with associated Essential Elements of Information (EEI), data type, and analyst/user preferences. As the mission progresses, ISR-CSS incorporates adaptive parameter updates (model-based, statistics-based, learning-based, event-driven), allowing for an increase of tactical relevancy of the data. If the mission transforms absolutely, where

unexpected guidance is now required, then ISR-CSS allows tactical end-user direct-to-sensor tasking. To address information overload, ISR-CSS filters and prioritizes data according to end-user preferences. ISR-CSS dispenses mission-critical and timely actionable information for end-user utilization, enabling faster response to a greater range of threats across the mission spectrum.

8360-14, Session 4

Robust tracking and anomaly detection in video surveillance sequences

H. F. Rueda, Univ. Industrial de Santander (Colombia); L. F. Polania, K. E. Barner, Univ. of Delaware (United States)

Anomaly detection systems should offer low false alarm rates under challenging scenarios given that misclassification can result in critical errors. This paper focuses on improving current tracking algorithms based on the emerging area of sparse and low rank matrix decomposition via convex optimization by incorporating a preprocessing light normalization stage and exploiting three dimensional correlation between consecutive frames using mathematical morphology to remove clutter and filling holes in incomplete objects. In particular, the tracking is treated as a background/foreground decomposition problem, where the static part corresponds to the background and the moving objects to the foreground. Therefore, the matrix decomposition is formulated as $X=L+S+E$, where X is the captured scene, L is the low-rank part (background), S is the sparse part (foreground) and E is the corrupting noise introduced in the capture process. Here we compare the performance improvement of three different algorithms in solving the matrix decomposition problem when the light normalization and mathematical morphology stages are incorporated: Robust Principal Component Analysis (RPCA) using augmented lagrange multiplier method, Bayesian RPCA and GoDec, which is an algorithm based on bilateral random projections. Experimental results show that the proposed method appears very promising when tracking under light variations and offers high precision and low false alarm when detecting novel intrusions.

8360-15, Session 4

A static architecture for compressive target tracking

P. K. Poon, The Univ. of Arizona (United States); D. Townsend, S. Wehrwein, The MITRE Corp. (United States); E. M. Vera, The Univ. of Arizona (United States); M. D. Stenner, The MITRE Corp. (United States); M. E. Gehm, The Univ. of Arizona (United States)

Traditional approaches to persistent surveillance generally contain large-format detector arrays and expensive objective optics. These systems generate prodigious amounts of data, stressing storage, communication, and analysis systems. As such, they are well suited for potential applications of compressed sensing (CS) concepts. This is particularly the case when target tracking is the application of interest-the difference between two consecutive views of the scene (at sufficient framerate) is nonzero only at the locations in the scene that have changed, and is therefore natively sparse.

Existing demonstrations of compressive target tracking have typically utilized time-sequences of random patterns as the measurement kernel. A time-sequential approach is limited in real-world applications as it fails against dynamic scenes and limits the available exposure time on static scenes. We have been investigating an alternative compressive target tracking architecture that we term SCOUT-Static Computational Optical Undersampled Tracker. The SCOUT architecture uses a pair of static masks and a defocused detector to create a shift-variant system PSF. The result is that a small number of parallel measurements can be used to localize movers with high spatial resolution in a snapshot manner.

We will report on our working experimental prototypes that have demonstrated successful target tracking at 16x compression under a variety of conditions.

8360-16, Session 4

Parallax visualization of UAV FMV and WAMI imagery

C. A. Mayhew, C. M. Mayhew, Vision III Imaging, Inc. (United States)

The US Military is increasingly relying on the use of unmanned aerial vehicles (UAV) for intelligence, surveillance and reconnaissance (ISR) missions. Complex arrays of full motion video (FMV) and wide area motion imaging (WAMI) technologies are being deployed on UAV platforms for ISR applications. However, these systems are only as effective as the Image Analyst's ability to extract relevant information from the data.

A variety of tools assist in the analysis of imagery captured with UAV sensors. However, until now none have been developed to extract and visualize parallax three-dimensional information.

Parallax Visualization (PV) is a technique that produces a near-three-dimensional visual response to standard UAV imagery. The overlapping nature of UAV imagery lends itself to parallax visualization. Parallax differences can be obtained by selecting frames that differ in time and therefore points of view of the area of interest.

PV is accomplished using software tools to critically align a common point in two views while alternately displaying both views in a square-wave manner. Humans produce an autostereoscopic response to critically aligned parallax information presented on a standard unaided display at between 3 and 6 Hz.

This simple technique allows for the exploitation of spatial and temporal differences in image sequences to enhance depth, size, and spatial relationships of objects in areas of interest. PV of UAV imagery has been successfully performed in several US Military exercises over the last two years. The Authors' paper will report on the theory and practical application of parallax visualization of UAV ISR data.

8360-17, Session 4

Kalman filter outputs for inclusion in video-stream metadata: accounting for temporal correlation of errors for optimal target extraction

J. Dolloff, Integrity Applications, Inc. (United States)

A video-stream associated with an Unmanned System or Full Motion Video can support the extraction of ground coordinates of a target of interest. The sensor metadata associated with the video-stream includes a time series of estimates of sensor position and attitude, required for down-stream single frame or multi-frame ground point extraction, such as stereo extraction using two frames in the video stream that are separated in both time and imaging geometry. The sensor metadata may also include a corresponding time history of estimate accuracy (error covariance). This is required for optimal down-stream target extraction as well as corresponding reliable predictions of extraction accuracy. However, for multi-frame extraction, this is only a necessary condition. The temporal correlation of estimate errors (error cross-covariance) between an arbitrary pair of video frames is also required. When the estimates of sensor position and attitude are from a Kalman filter, as typically the case, the corresponding error covariances are automatically computed and available. However, the cross-covariances are not. This paper presents an efficient method for their exact representation in the meta-data using additional, easily computed, data from the Kalman filter. The paper also presents an optimal weighted least squares extraction algorithm that correctly accounts for the temporal correlation, given the additional metadata. Simulation-based examples are presented that show the importance of correctly accounting for temporal correlation in multi-frame extraction algorithms.

8360-18, Session 4

Automated assessment of video image quality: implications for processing and exploitation

J. M. Irvine, Draper Lab. (United States)

Several methods have been developed for quantifying the information potential of imagery exploited by a human observer. The National Imagery Interpretability Ratings Scale (NIIRS) has proven to be a useful standard for intelligence, surveillance, and reconnaissance (ISR) applications. Extensions of this approach to motion imagery have yielded a body of research on the factors affecting interpretability of motion imagery and the development of a Video NIIRS. Automated methods for assessing image interpretability can provide valuable feedback for collection management and guide the exploitation and analysis of the imagery. Prediction models that rely on image parameters, such as the General Image Quality Equation (IQE), are useful for conducting sensor trade studies and collection planning. Model for predicting image quality after image acquisition can provide useful feedback for collection management. Several methods exist for still imagery. This paper explores the development of a similar capability for motion imagery. In particular, we propose methods for predicting the interpretability of motion imagery for exploitation by an analyst. A similar model is developed for automated exploitation. We present the two models and compare their performance.

8360-19, Session 5

Degraded environments and ESVS applications

J. J. Guell, The Boeing Co. (United States)

A Top Level perspective/summary of various degraded environments of interest, including DVE (Degraeded Visual Environments), and what Enhanced & Synthetic Vision Systems can do in order to provide solutions to various applications.

8360-20, Session 5

Operational requirements for short-term solution in visual display specifically for DVE

T. W. Eger, German School of Army Aviation (Germany)

In order to assist the pilot to safely control and land the helicopter in degraded visual environment (DVE), an integrated system of various technologies that will provide improved situation awareness (SA) with minimal interpretation whilst controlling the aircraft is essential. For the landing task, SA should include information about the landing site and flight parameters such as height, heading speed, drift, and rate of descent. The development of such integrated system is a long term goal. Most of the current, legacy helicopters do not provide a specific display for landing or operating at a remote and unfamiliar landing zone (LZ) in DVE. In order to ensure a safe landing, visual cues that will provide drift, height above terrain (HAT), descent rate, ground speed, attitude, slope, terrain features, LZ location, obstacle clearance and moving obstacle detection that are mission related must be available. Therefore, a short term solution, especially to upgrade legacy aircraft, is the development of alternative visual displays adapted to low speed landing for operations in DVE. For example, visual cues used for takeoffs and landings can be replaced by virtual references. While other display symbology incorporates different speed schedulers and rising ground/vertical speed combined symbols. In addition, these displays can be 2 dimension vs. 3 dimension, conformal vs. non conformal, and head mounted vs. panel mounted. This presentation will provide an overview of requirements to operate legacy aircraft in todays missions and selected examples of visual displays specifically designed for landing in DVE as short term solutions.

8360-21, Session 5

Brownout landing aid system technology (BLAST): system overview and flight test results

B. Sykora, BAE Systems (United States)

Recent studies by the Joint Aircraft Survivability (JAS) Program Office and the Naval Aviation Center for Rotorcraft Advancement (NACRA) have reported that over 80% of rotorcraft losses are due to non-hostile actions with a majority of those related to degraded visual environments (DVE), resulting in loss of life and equipment costs of approximately $100 million per year. A material solution with an active sensor that provides pilots with visual awareness in DVE conditions is urgently needed.

BAE Systems has been developing a “see-through” brownout landing aid system technology (BLAST) over the past several years based on a small and light weight 94 GHz radar with proven ability to penetrate dust, coupled with antenna tracking, signal processing and digital terrain morphing algorithms to produce a cognitive 3D synthetic image of the ground and proximate surface hazards in and around the landing zone (LZ).

Flight tests of BLAST installed on a UH-1 at the Yuma Proving Grounds in 2011 have demonstrated the ability of the system to see through dust and accurately detect the location and height of objects and surface hazards at useful ranges to generate real time 3D synthetic images of the landing area.

The results of these flight tests have demonstrated the utility of BLAST in relevant environments to satisfy the urgent need for a brownout landing capability. The paper will include a more detailed overview of BLAST including key attributes and performance characteristics, operational concepts, descriptions of the flight tests conducted, and samples of test results.

8360-22, Session 5

LandSafe aircraft survivability system: the DVE solution

P. Mamidipudi, E. Dakin, D. Dakin, Optical Air Data Systems, LLC (United States)

Helicopter landing and take-off operations in degraded visual environments (DVE) have become an integral part of military operations. Downwash from the main rotor can create intense and blinding dust clouds that quickly surround the helicopter and result in complete loss of situational awareness for pilots and flight crews.

Optical Air Data Systems (OADS) L.L.C. has designed, prototyped, and flight-tested a laser remote sensing system that provides precise height above ground, groundspeed, ground drift, and low speed airspeed information to the pilot in real time under DVE conditions. The LandSafe® system is a rugged all-fiber laser system that operates on the principle of Laser Doppler Velocimetry (LDV). Precisely tailored Class I eye-safe laser pulses from independent optical heads simultaneously interrogate the ground below the aircraft and a clear volume of air outside the rotor wash to accurately measure aircraft altitude, drift over the ground, as well as low speed airspeed. Customized signal processing algorithms are then utilized to discriminate between returns from the scatterers (such as dust or sand) and the ground. This information is collected and processed in real-time at a rate of 10 Hz and displayed to the pilot.

The paper will discuss the performance characteristics of this sensor system in detail and present AGL, ground speed, and airspeed data collected from the sensor system in clear air and DVE conditions over a series of test flights on multiple helicopter platforms.

8360-23, Session 5

Advanced distributed aperture system

T. L. Bushell, Raytheon Network Centric Systems (United States)

Background: ADAS addresses several critical requirements identified during operations in Iraq and Afghanistan, and confirmed in the congressionally-directed 2009 Study on Rotorcraft Survivability. These critical requirements include cruise flight improved terrain warning awareness, low speed and hover degraded visual environment awareness, improved awareness of guided weapons, and improved awareness of ballistic weapons, including small arms.

A technology demonstration contract was awarded in 3Q FY08 to develop pilotage situational awareness capabilities to a pre-prototype level maturity and to demonstrate this emerging technology in flight demonstrations. In 2009 development of ballistic weapons Hostile Fire Indication (HFI), Degraded Visual Environment (DVE) enhancements, and 3D audio and helicopter specific active noise reduction (ANR).were added. In 2011 A prototype HFI system, the 3D audio and ANR with full spherical MWIR/NIR fusion, as an ADAS integrated package was flown and demonstrated

8360-24, Session 6

Evaluation of DVE landing display formats

H. Doehler, P. M. Knabl, S. Schmerwitz, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); T. W. Eger, German School of Army Aviation (Germany); O. Klein, Elbit Systems Ltd. (Israel)

Within the recent years many different proposals have been published about the best design of display contents for helicopter pilot assistance during DVE landing. The guidance cues are typically shown as an overlay possibly on top of additional sensor or database imagery. This overlay represents the main information source for helicopter pilots during an instrument landing procedure. Display technology within this field applies two different principles: Multicolor head-down display (panel mount), and monochrome head-up display (head mounted). For both types the state-of-the-art imagery doesn't make use of conformal symbology sets. They rather expose the pilots to mixed views (2dimensional forward and bird's eye view). Even so the trained pilots can easily interpret the presented data it doesn't seem to be the best design for head-up displays.

A study was realized to compare different state-of-the-art symbology sets (e.g. BOSS, DEVILA and JEDEYE). During landing trials in our helicopter simulator these different formats were presented to the pilots on head-down and helmet-mounted displays. The evaluation of this study is based on measured flight guidance performance (objective measures) and on questionnaires (subjective measures). The results can pave the way for the planed development of a new conformal wide field of view perspective display for DVE landing assistance.

8360-25, Session 6

Use of 3D conformal symbology on HMD for a safer flight in degraded visual environment

O. Klein, Elbit Systems Ltd. (Israel); H. Doehler, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

HMD legacy symbology presents usually numbers and symbols referring to the aircraft data (speed, velocity, distance to LZ etc.)

This type of symbology is used in large amount of platforms including fighters, transport aircraft and helicopters.

A head-tracked 3D conformal symbology displays the symbology on the real world, same as Augmented Reality concept.

In order to create the symbology with acceptable performance for the pilots, use of aircraft sensors, advanced low-latency HMD tracker and advanced algorithms are used.

A major advancement in the performance of head traced systems in the recent years made this concept acceptable for flight, while testing and evaluating the systems in simulators and test flights.

Pictures and movies from trials among technology overview will be presented.

8360-26, Session 6

Developing an obstacle display for helicopter brownout situations

N. Peinecke, P. M. Knabl, S. Schmerwitz, H. Doehler, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Project ALLFlight is DLR's initiative to diminish the problem of piloting helicopters in degraded visual conditions. The problem arises whenever dust or snow is stirred up during landing (brownout/whiteout), effectively blocking the crew's vision of the landing site. A possible solution comprises the use of sensors that are able to look through the dust cloud. As part of the project display symbologies are being developed to enable the pilot to make use of the rather abstract and noisy sensor data.

In a first stage sensor data from very different sensors is fused. This step contains a classification of points into ground points and obstacle points.

In a second step the result is augmented with ground data bases and depicted in a synthetic head-down display.

Regarding the design, several variations in symbology are considered, including variations in color coding, continuous or non-continuous terrain displays and different obstacle representations.

In this paper we present the basic techniques used for obstacle and ground separation. We choose a set of possibilities for the pilot display and detail the implementation.

Furthermore, we present a pilot study, including human factors assessment with focus on usability and pilot acceptance.

The validation involves user standard questionnaires on operational feasibility, covering aspects such as comprehensibility, readability, visibility, perceptibility and comfort of use. Further, questionnaires in operational improvements in terms of safety and human factors such as situation awareness and workload are assessed.

Beyond standard questioning methods tailor made questionnaires are compiled to check the fulfilment of operational requirements.

8360-27, Session 6

Weighting functions for multispectral image fusion

G. A. Reis, A. R. Pinkus, D. W. Dommett, F. Mohd-Zaid, J. Hasbrouck, Air Force Research Lab. (United States)

There is growing interest in the field of multispectral image fusion as the benefits of fusion are realized and as the number, in quantity, and in diversity, of sensors increases. Multispectral image fusion has the benefits of combining multiple images into one image to provide reliability and redundancy for uncertainty reduction as well as providing complementary information into one image that would not have been available in each input image separately. However, instances of information loss may occur through image fusion-where information from the input images is not apparent in the fused image. We investigate weighting methodologies that display a continuum of fused images of the same scene, from one input image, weighted through the fused image, and to the other input image. We discuss this methodology in the context of a video analyst's (real-time and forensic) perception and performance (finding, recognizing, and tracking targets). The proposed method also has implications for attention and cueing. We discuss subjective, algorithmically objective, physiological, and performance-based metrics for evaluation of such a fusion methodology towards attenuating inattentional blindness and information loss in image fusion. The fusion methodology is also examined under various fusion algorithms

and operator interaction with the displaying of the continuum of fused imagery.

8360-28, Session 6

High dynamic range fusion for enhanced vision

Y. Liu, Tsinghua Univ. (China) and Radar Academy (China); Y. Li, Q. Dai, Tsinghua Univ. (China)

Fusing multispectral images, Enhanced Vision (EV) has been proven helpful to improve pilot's Situation Awareness (SA) under Degraded Vision Environment, such as low visibility or adverse observation conditions, which caused by fog, dust, weak light, backlighting, etc. Numerous methods are applied to enhance and fuse optical and infrared (IR) images for visual details to provide pilot with enough information as far as possible. However, most existing optical and IR imaging devices, for their inherent defects, fail to acquire wide span of light and only generate Low Dynamic Range images (LDR, Dynamic Range: range between the lightest and darkest areas), which causes the loss of useful details. Normal display devices can't reveal HDR details as well.

The proposed paper introduces and expands High Dynamic Range (HDR) technologies to fuse optical and IR images, which has rarely been involved in the study of HDR Imaging to our knowledge, for Enhanced Vision to better pilot's Situation Awareness. Two major problems are discussed. (1) The way to obtain HDR images from both optical and IR LDR images from Degraded Vision Environment for fusion. Firstly, both optical and IR LDR images are filtered to remove noise and increase textures and contours. Then, methods are proposed for HDR information generation from optical and IR LDR images respectively. Finally, two HDR images are fused. (2) The method to effectively display details from fused HDR image on normal LDR monitors. Tone Mapping methods are tested to select the appropriate one. The experimental result proves that our method is effective to enhance observer's situation awareness under degraded vision environment.

This paper is supported by National Basic Research Program of China (973 Program, No. 2010CB731800), which focuses on aircraft's approaching under complex situations including Degraded Vision Environment.

8360-29, Session 7

Visual information, sparse decomposition, and transmission for multi-UAV visual navigation

H. Liu, Q. Dai, Tsinghua Univ. (China)

In recent years, visual navigation of UAVs has been an active area of research. There is a large amount of visual information to be processed and transmitted with real-time requirements for the flight scenes change rapidly. However, it has already become one of the major factors of blocking the cooperative communication in multi-UAV visual navigation. The traditional video image orthogonal decomposition methods can not be well adapted to the multi-UAV visual navigation system, because with the compression ratio increases, there is a sharp decline in video image quality. This paper proposes a novel visual information sparse decomposition and transmission (VSDT) method for multi-UAV visual navigation.

In the method, aiming at the visual information characteristics, firstly we pre-process the video images by introducing a multi-scale visual information acquisition mechanism. Then a fast video image sparse decomposition is made for transmission. It can greatly reduce the original video information amount, while the quality of visual information needed for navigation is guaranteed. Finally, based on the task requirements, data correlations and feature matching, we design a real-time transmission scheme to make the receiver UAV can quickly reconstruct the flight scene information for navigation. The simulated results are presented and discussed.

The main advantage of this method lies in the ability to reduce the visual information transmission amount while ensuring the quality of visual information needed for navigation and solve the cooperative communication problems such as information lag, data conjunction and match error often encountered in multi-UAV visual navigation environment.

8360-30, Session 7

Enhancement of vision systems based on runway detection by image processing techniques

N. Gulec, Sabanci Univ. (Turkey) and SDT A.S. (Turkey); N. Sen Koktas, SDT A.S. (Turkey)

An explicit way of facilitating approach and landing operations of aircraft in degraded visual environments is presenting a coherent image of the designated runway via vision systems and hence increasing the situational awareness of the flight crew. Combined vision systems, in general, aim to provide a clear view of the aircraft exterior to the pilots using information from databases and imaging sensors. This study presents a novel method that consists of image-processing and tracking algorithms, which utilize information from navigation systems and databases along with the videos from daylight and infrared cameras, for the recognition and tracking (through the approach and landing) of the designated runway. Video data simulating the straight-in approach of an aircraft from an altitude of 5000 ft down to 100 ft is synthetically generated by a COTS tool. A diverse set of atmospheric and meteorological conditions such as rain, fog, low light levels in the experiments. Detection and false alarm rates (DT, FAR) are used as the primary performance metrics. The results are presented in a format where the performance metrics are compared against the altitude of the aircraft. Depending on the visual environment and the source of the video, the performance metrics reach up to 98% for DR and down to 5% for FAR.

8360-33, Session 7

Airplane vertical situation awareness

W. F. Spencer V, The Boeing Co. (United States)

No abstract available

8360-34, Session 7

Vertical situational awareness (SA) extensions for rotorcraft

W. F. Spencer V, The Boeing Co. (United States)

No abstract available

8361-01, Session 1

Interferometric measurement of the angular velocity of moving humans

J. A. Nanzer, The Johns Hopkins Univ. Applied Physics Lab. (United States)

This paper presents an analysis of the measurement of the angular motion of walking humans using a microwave correlation interferometer. Measurement of the angular motion of moving objects is a desirable function is remote sensing applications. Doppler radar sensors are able to measure the signature of moving humans based on micro-Doppler analysis; however, a person moving with little to no radial velocity produces negligible Doppler returns. Measurement of the angular movement of humans can be done with traditional radar techniques, however the process involves either continuous tracking with narrow beamwidth or angle-of-arrival estimation algorithms.

A new method of measuring the angular velocity of moving objects using interferometry has recently been developed. The method measures the angular velocity of an object without tracking or complex processing. The frequency of the interferometer signal response is proportional to the angular velocity of the object as it passes through the interferometer beam pattern. In this paper, the theory of the interferometric measurement of angular velocity is covered and simulations of the response of a walking human are presented. System parameter tradeoffs are discussed which affect the performance of the measurement system. Simulations are produced using a model of a walking human to show the significant features associated with the interferometer response, which may be used in classification algorithms.

8361-02, Session 1

Adaptive waveform scheduling in radar: an information theoretic approach

P. Setlur, N. Devroye, Univ. of Illinois at Chicago (United States)

In this paper, the problem of adaptively selecting waveforms from a pre-defined library of waveforms is addressed from an information theoretic perspective. Typically, radars transmit specific waveforms periodically, to obtain for example, the range as well as the Doppler of a target. Although modern radars are more than capable of transmitting different waveforms during each consecutive period of transmission, it is hitherto unclear as to how these waveforms must be scheduled to best understand the nature of the radar scene. In reality, reception of radar returns for a particular transmitted waveform already encapsulates knowledge about the scene, which is difficult to incorporate in scheduling the next waveform. Nevertheless, and not surprisingly information theory provides a correct framework to quantify as well as employ this knowledge to aid in scheduling the next waveform to be transmitted. Such adaptive radars may thus be more efficient than their traditional counterparts.

In the past literature on radar waveform design and scheduling, emphasis has been placed on the heuristic use of mutual information as a metric or objective function to maximize or minimize. We too argue that mutual information, as well as its ``directed” counterpart, the directed information which captures some of the closed loop aspects of the cognitive radar problem, is of relevance in this problem which may be viewed a special uncoded, joint source-channel coding problem. We study the relationship between optimizing mutual versus directed information in the closed loop radar waveform scheduling setting and will see that, under certain conditions, the directed information equals the mutual information.

A standalone single antenna radar system is assumed with access to a pre-defined waveform library. The target is assumed to be complex or extended with an impulse response being modeled by a stationary Gaussian random process. Simulations and analytical insights finally demonstrate when adaptive transmission is either warranted, or unwarranted depending on the nature of the target statistics as well as the statistics of the noise plus interference. In formulating the problem, important analytical insights to well known Bayesian error metrics are also provided.

8361-03, Session 1

Testing a transmission line model for homogeneous subsurface media using ground-penetrating radar

B. Rodriguez Hervas, The Univ. of Texas at El Paso (United States)

Ground Penetrating Radars (GPR) process electromagnetic reflections from subsurface interfaces to characterize the subsurface and detect buried targets. Our objective is to test an inversion algorithm that calculates the intrinsic impedance of subsurface media when the signal transmitted is modeled as the first or second derivative of a large bandwidth Gaussian pulse. For this purpose we model the subsurface as a transmission line with multiple segments, each having different propagating velocities and characteristic impedances. We simulate the propagation and reflection of the pulse from multilayered lossless and lossy media, and process the received signal with a rectifier and filter subsystem to estimate the impulse response. We then run the impulse response through the inversion algorithm in order to calculate the relative permittivity of each subsurface layer. We show that the algorithm is able to detect targets using the primary reflections, even though secondary reflections are sometimes required to maintain inversion stability. We also demonstrate the importance of compensating for geometric spreading losses and conductivity losses to accurately characterize each substrate layer and target. Such compensation is not trivial in experimental data where electronic range delays can be arbitrary, transmitted pulses often deviate from the theoretical models, and limited resolution can cause ambiguity in the range of the targets.

8361-04, Session 1

High-resolution time-frequency representations based on the local polynomial Fourier transform for over-the-horizon radars

I. Djurovic, S. Djukanovic, Univ. of Montenegro (Montenegro); M. G. Amin, Y. D. Zhang, Villanova Univ. (United States)

Over-the-horizon radar (OTHR) performs wide-area surveillance at ranges well beyond the limit of conventional line-of-sight (LOS) radars [1]. Maneuvering targets generate multi-component Doppler signatures corresponding to the direct and non-direct paths, both encounter reflections from the ionosphere. These signatures contain important information about the position, maneuvering and altitude of the targets, and they are usually characterized by significant variation of their instantaneous frequencies (IFs). If properly estimated, the multi-component target Doppler signatures reveal the moving target altitude trajectories. Time-frequency (TF) methods can be successfully applied for high-resolution analysis of the OTHR Doppler returns [2]. Clearly, the main challenge facing parametric and nonparametric time-frequency representation methods in OTHR is the ability to resolve close signal components arising from close Doppler values when the aircraft is viewed by different multipaths. It is noted that in the TF plane, the Doppler components can be only several frequency bins apart and even visual detection could be hardly done. High-resolution methods, such as the Capon and the MUSIC techniques, cannot be applied due to the IF variations. The use of bilinear TF signal representations, either in non-adaptive or adaptive mode, is also restricted due to inherent interferences. The spectrogram, which is a very popular TF tool, has poor resolution for such OTHR Doppler signals.

In this paper, we propose a hybrid TF-based method for resolving OTHR Doppler returns. The method comprises several recently proposed tools and its superior performance compared to other competing TF methods is validated using real and simulated data. First, the Viterbi algorithm-based IF estimator [3] is used to detect the TF-domain positions of the signal of interest in heavily cluttered data. After detecting regions of interest, the local polynomial Fourier transform (LPFT) is used to produce high-resolution TF representation without cross-terms [4]. In the LPFT, the adaptive chirp-rate is estimated at each time instant and selected to compensate higher order terms in the signal's IF and, as such, improve the signal concentration. Finally, an efficient high-resolution interpolation strategy is used to refine the estimation of the considered signal component.

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8361-05, Session 2

Refocusing vibrating targets in SAR images

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In synthetic-aperture radar (SAR) returned signals, ground-target vibrations introduce a phase modulation that is linearly proportional to the vibration displacement. Such modulation, termed the micro-Doppler effect, introduces ghost targets along the azimuth direction in reconstructed SAR images that prevents SAR from forming focused images of the vibrating targets. Recently, a discrete fractional Fourier transform (DFRFT) based method was developed to estimate the vibration frequencies and instantaneous vibration accelerations of the vibrating targets from SAR returned signals. In this paper, a demodulation-based algorithm is proposed to reconstruct focused SAR images of vibrating targets by exploiting the estimation results of the DFRFT-based vibration estimation method. For a single-component harmonic vibration, the history of the vibration displacement is first estimated from the estimated vibration frequency and the instantaneous vibration acceleration. Then a reference signal whose phase is modulated by the estimated vibration displacement with a delay of 180 degree is constructed. After that, the SAR phase history from the vibration target is multiplied by the reference signal and the vibration-induced phase modulation is canceled. Finally, the re-focused SAR image of the vibration target is obtained by applying the 2-D Fourier transform to the demodulated SAR phase history. This algorithm is applied to simulated SAR data containing both vibrating targets and clutters under different signal-to-noise ratios. The algorithm successfully reconstructs focused SAR images of the vibrating targets with different vibrating frequencies and amplitudes.

8361-06, Session 2

3D ISAR image reconstruction of targets through filtered back projection

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In this paper, an inversion scheme for near-field inverse synthetic aperture radar (ISAR) data is derived for both two and three dimensions from a scalar wave equation model. The proposed data inversion scheme motivates the use of a filtered back projection (FBP) imaging algorithm. The paper provides a derivation of the the general imaging filter needed for FBP, which will be shown to reduce to a familiar result for near-field ISAR imaging.

8361-07, Session 2

Features for landcover classification of fully polarimetric SAR data

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It has been shown that Stokes eigenvectors can be extracted from the Kennaugh matrices of both single-look and multilook fully polarimetric SIR-C data. The orientation and ellipticity parameters of the Stokes eigenvector are identical with the Huynen orientation and helicity parameters for single-look fully polarimetric SIR-C data. These are also the parameters which diagonalize the Sinclair matrices of the single-look data. The Kennaugh matrices of single-look data have five independent parameters. The Kennaugh matrices of multi-look data have nine independent parameters. These parameters will be combined with target decomposition parameters, such as those from the Krogager decomposition, to generate features for input into a multilayer neural net classification scheme for landcover classification of fully polarimetric synthetic aperture radar(SAR) data. Initial results will be reported.

8361-08, Session 2

Accurate reconstruction of frequency-sparse signals from non-uniform samples

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With the advent of a new sampling theory in recent years, compressed sensing (CS), it is possible to reconstruct signals from measurements far below the Nyquist rate. This technique assumes that signals are sparse and that measurement matrices satisfy certain conditions. Even though there have been many promising results in CS theory, unfortunately there still exists a gap between the theory and actual real world applications. This is because of the fundamental problem that CS formulation is discrete.

We propose a sampling and reconstructing method for frequency-sparse signals that addresses this issue. The signals in our scenario are supported in a continuous sparsifying domain rather than discrete. By the nature of the frequency-sparse assumption, this is a parameter estimation problem; and directly looking for frequencies and amplitudes that best fit the measurements is a non-convex optimization problem. We show sufficient conditions for this problem to be convex and hence make the solutions tractable.

Our approach extends the utility of CS. We take direct measurements from non-uniform time-samples, which reduces to the CS problem with a subsampled Fourier matrix if frequencies fall on the grid. The proposed reconstruction algorithm iteratively approximates the solutions using CS and then accurately solves for the frequencies with Newton's method and for the amplitudes with least squares solutions.

In our simulations, we show that the proposed method is able to accurately reconstruct signals with arbitrary frequencies and significantly outperforms other spectral compressed sensing methods in terms of reconstruction fidelity for both noise-free and noisy cases.

8361-09, Session 3

Multifunctional millimeter-wave radar system for helicopter safety

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A multi-featured sensor solution has been developed that enhances the operational safety and functionality of small airborne platforms. This represents an invaluable stride toward enabling more high-risk and complex tactical missions in a variety of operational conditions. This paper will show the results from a recently developed multi-functional sensor system that integrates a high performance millimeter-wave radar front end, an evidence grid-based integration processing scheme, and the incorporation of the data into a 3D Synthetic Vision System (SVS) display as a potential solution for such applications. The front end architecture consists of a w-band real-beam scanning sensor that generates a high resolution real-time radar map with an adaptable antenna architecture that currently incorporates an interferometric capability for target height estimation. The raw sensor data is further processed within an evidence grid-based integration functionality that results in high-resolution maps in the region surrounding the platform. Lastly, the accumulated radar results are displayed in a fully rendered 3D SVS environment integrated with local database information to provide the best representation of the surrounding environment. The integrated system concept will be discussed and initial results from an experimental flight test of this developmental system will be presented. Specifically, the forward-looking operation of the system will demonstrate the system's ability to produce high precision terrain mapping with obstacle detection and avoidance capability, showcasing the system's versatility in a true operational environment. In addition, the proposed system concept can be shown to seamlessly accommodate additional sensors and operational modes that would satisfy other tactical requirements.

8361-10, Session 3

Flexible end-to-end system design for synthetic aperture radar applications

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This paper presents ARTEMIS, Inc.'s approach to development of end-to-end synthetic aperture radar systems for multiple applications and platforms. The flexible design of the radar and the image processing tools facilitates their inclusion in a variety of application-specific end-to-end systems. Any given application comes with certain requirements that must be met in order to achieve success. A concept of operation is defined which states how the technology is used to meet the requirements of the application. This drives the design decisions. Key to adapting our system to multiple applications is the flexible SlimSAR radar system, which is programmable on-the-fly to meet the imaging requirements of a wide range of altitudes, swath-widths, and platform velocities. The processing software can be used for real-time imagery production or post-flight processing. The ground station is adaptable, and the radar controls can be run by an operator on the ground, on-board the aircraft, or even automated as part of the aircraft autopilot controls. System integration takes the whole operation into account, seeking to flawlessly work with data links and on-board data storage, aircraft and payload control systems, mission planning, and image processing and exploitation.

Examples of applications are presented including using a small unmanned aircraft at low altitude with a line of sight data link, a long-endurance UAV maritime surveillance mission with on-board processing, and a manned ground moving target indicator application with the radar using multiple receive channels.

8361-11, Session 3

Radar-based full-body screening of passengers with constant motion

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The recent terror attacks showed the vulnerability of our public life. Especially. the terror attack at the terminal of the Moscow Domodedowo airport showed that the security checkpoints alone do not protect the airport sufficiently. The security concept has to be enhanced to the overall terminal in order to identify terrorists before or while entering the terminal. For this reason, in this paper a new security concept is introduced which is able to scan people moving with constant speed. In the conducted experiment, the person under test stands on a wagon which moves below the radar on a rail system. In practice, the persons would stand on a moving walkway or on a moving escalator. During this movement the person is screened to localise large weapons such as guns or explosive belts which could be used for killing multiple people. Metal detectors are inappropriate as they can only detect metal objects by the principle of the electromagnetic induction. Body scanners developed in the past years would do that but are also not applicable as they are just portal solutions which need still standing persons to perform the measurements. That is why a rotating radar system above the moving person is presented which performs a full body scan in just 4 seconds. The W band was used as millimetre waves give a good compromise between a high resolution and acceptable attenuations during the penetration through dielectric materials such as textiles. The radar consists of a FMCW module which sweeps the frequency between 96 GHz and 99 GHz by a varactor tuned voltage controlled oscillator. The conductor-backed coplanar waveguide technology in combination with metamorphic cascode HEMTs has been demonstrated to be highly suitable for the development of millimetre-wave low-noise heterodyne receiver MMICs. The radar consist of 5 receive channels in order to capture back scattered energy from different aspect angles. The presented 4 channel receiver operates between 84 GHz and 104 GHz and achieved a maximum conversion gain of 12 dB and an average noise figure of 3.5 dB. Moreover, a simple 90 degree turning of the used horn antennas allow an easy variation of the polarisation and thus polarimetric measurements which are helpful for the identification of oblong objects such as explosive tubes. The received intermediate frequency data are processed by the principle of the synthetic aperture.

8361-12, Session 3

Radar tracking and classification of littoral targets

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Radar can provide inexpensive wide-area surveillance of river and port traffic for both security and emergency response. We demonstrate the tracking of multiple vessels as well as the micro-Doppler signatures of different classes of small vessels, including kayaks and zodiacs. The pattern of life of a river is analyzed over several days and can be used to easily identify suspicious or unusual cases.

8361-13, Session 3

Analysis of spaceborne, fully polarimetric SAR data

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This paper present the results of the scientific analysis of fully polarimetric SAR data. The primary focus is on the classification of

different surface types of semid aread areas using the entropy/alpha algorithm. The eight different scattering classification proerties will be additionally investigated by the analysis of polarimetric signatures. The inicial results are corrupted by noise. In order to get a clear discrimination different type of filter algorithms are applied. A second type of analysis investigates the Huynen parameters. The interpretation of this parameter set will be discussed.

8361-14, Session 3

3D synthetic aperture processing on high-frequency, wide-beam, microwave systems

E. Cristofani, A. Brook, M. Vandewal, Royal Belgian Military Academy (Belgium)

The use of High-Frequency MicroWaves (HFMW) for high-resolution imagery has gained interest over the last years. Very promising in-depth applications can be foreseen for composite, non-polarized materials, widely used in the aeronautic and aerospace industries. Most of these materials present a high transparency in the HFMW range and, therefore, defects, delaminations or inclusion within the material can be located. The classical approach to 3D HFMW imaging is based on focusing the emitted beam by enlarging the antennas, ensuring a small spot size on the material. The in-depth resolution is determined by the transmitted bandwidth. Instead of reducing the spot size to enhance the cross-range resolution, a different approach such as Synthetic Aperture (SA) radar can be addressed. An end-to-end 3D imagery system for short-range Non-Destructive Testing is presented based on a Frequency-Modulated Continuous-Wave (FMCW) HFMW sensor operating at 100 GHz, implying relatively low costs and power requirements. The sensor moves sequentially in elevation and azimuth while scanning and uses a wide beam antenna, in contrast to classical imaging systems. Collected data is coherently combined using a SA algorithm to form focused images. Constant range and synthetically improved cross-range resolutions are remarkable added values of SA. Such algorithms operate in the time or frequency domain, being the former computationally impractical and the latter the best option for in-depth imaging. A balanced trade-off between performance and spatial resolution for several SA algorithms, non-linear signal propagation caused by abrupt changes in refraction indices due to material interfaces, and motion compensation will be studied.

8361-15, Session 4

SAR change detection for monitoring the impact of the rehabilitation of the Arghandab irrigation system in Afghanistan

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Tracking the progress and impact of large scale projects in areas of active conflict is challenging. In early 2010, the Canadian International Development Agency (CIDA) broke ground on an ambitious project to rehabilitate a network of over 40 km of canals that supply water from the Arghandab River throughout southern Kandahar Province thereby restoring a reliable and secure water supply and stimulating a once vibrant agricultural region. Monitoring the region for signs of renewal is difficult due to the large areal extent of the irrigated land and security concerns. With the support of the Canadian Space Agency, polarimetric change detection techniques are applied to space-borne SAR data to safely monitor the area through a time-series of RADARSAT-2 images acquired during the rehabilitation ground work and subsequent growing seasons. Change detection maps delineating surface cover improvement will aid CIDA in demonstrating the positive value of Canada's investment in renovating Afghanistan's irrigation system to improve water distribution. This paper examines the use of value-added SAR imaging products to provide short- and long-term monitoring suitable for assessing the impact and benefit of large scale projects and discusses the challenges integrating sensing products into a non-expert user community.

8361-16, Session 4

Detection of clandestine tunnels in complex environments using a mobile focused-source electromagnetic data measurement and interpretation unit

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We have developed a new technology for detecting and imaging underground tunnels - the Tunnel Detection Focused-Source Electromagnetic (TD-FSEM) method. It uses four horizontal electric dipole transmitters and a five-electrode grounded quadrupole receiver unit to measure the transient EM field. Such a setup directs the exciting current under the receiver vertically downward, increasing the sensitivity to a relatively narrow column of rocks directly below the receiver. The TD-FSEM method requires grounded receiving and transmitting electrodes, however, perfect grounding is not necessary. Presented 3DEM modeling results show that having not perfectly equal grounding impedances of the electrodes may result in different weights of the four measurements, but the results, after applying the automatic focusing post-processing, are practically undisturbed. This flexibility of the acquisition unit accelerates surveying speed.

Our previously published feasibility modeling results allowed us to prove the concept by showing that the method provides data sufficient for reliable detection of deep clandestine tunnels embedded in relatively low-resistivity ($\rho bg \leq 20 \Omega m$) homogeneous subsurface environments. In this paper, we present the comprehensive 3DEM modeling study results to assess the depth of investigation of the method to detect and resolve tunnels of different sizes in presence of complex resistivity profiles of the overburden and underburden layers situated above and below the target, respectively. We show that the TD-FSEM, unlike conventional EM sounding and GPR methods, allows for automatic removal of unwanted shallow/near-surface masking effects and it is relatively insensitive to the underburden layer. These unique features of our method enable application of a fast automatic subsurface imaging executed during the EM data acquisition using a mobile TD-FSEM data measurement and interpretation unit.

8361-17, Session 4

Cooperative control of MAVs for a hidden emitter localization

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This paper provides a summary of the development of a three-state cooperative control algorithm, applied to multiple Unmanned Aerial Vehicles (UAVs) or Micro-Aerial Vehicles (MAVs) that are used in cooperative search of a hidden electromagnetic source (emitter) in a controlled environment. MAVs are equipped with wireless sensor nodes capable of sensing an electromagnetic (EM) field around them. Simultaneous control and sensing capabilities of these MAVs are presented. The algorithm is using a three-state machine to control the MAVs. The first state is a decentralized cooperative search that allows MAVs to obtain information about the environment and detect EM emissions from the target as quickly as possible. The second state implements a gradient descent algorithm in which the MAVs converge towards the target based on the received signal strength, while still maintaining a proximal distance from each other. MAVs are positioned at the optimal distance of the detected EM source before fine-tuning of the emitter localization is carried out. The third state incorporates a technique called Position-Adaptive Direction Finding (PADF), where the MAVs

adapt their positions in order to further improve localization of a hidden emitter using an estimated path loss exponent as a feedback. We present simulation and experimental data that illustrate the proposed approach.

8361-18, Session 5

Synthetic aperture radar imaging of a two-story building

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The importance of countering asymmetric threats in an urban battlefield environment has prompted several defense agencies to sponsor the development of sensors capable of detecting targets inside buildings when no direct line-of-sight is available. Imaging ultra-wideband (UWB) radar, operating typically at low-frequencies (below 4 GHz) is one of the most promising technologies that offer such capabilities. Two major requirements for this technology consist of building layout reconstruction (via imaging) and through-wall dismount personnel detection. The electromagnetic modeling group at the U.S. Army Research Laboratory (ARL) has been active in both areas since 2004.

This paper investigates the expected performance of a multi-story building imaging radar system through computer models. First we created realistic computer aided design (CAD) models of a complex two-story building, containing multiple rooms, furniture, appliances and humans down to a fine level of detail. Next we simulated the radar response from this complex target, for a wide range of frequencies and aspect angles (both in azimuth and elevation). Finally, we created synthetic aperture radar (SAR) images for various geometries, including far-field or near-field, spotlight or strip-map, ground-based or airborne, high- or low-resolution. The numerical results give us a wealth of insight into the phenomenology of the scattering and imaging processes and emphasize the difficulty of obtaining reliable information on the building layout based on images formed in a single elevation plane. We demonstrate how combining images from different elevations and sides of the building can be used to infer information on the interior walls and possible targets placed inside.

8361-19, Session 5

Indoor imagery with a 3D through-wall synthetic aperture radar

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Through-wall radar imaging is an emerging technology with great interest to military forces operating in an urban battlefield. The through-wall imaging radar can potentially provide interior room layouts as well as detection and localization of targets of interest. In this paper, we present our through-wall radar system mounted on the side of a vehicle and driven along a path in front of a building of interest. The vehicle is equipped with a LIDAR (Light Detection and Ranging) and motion sensors that provide auxiliary information. The radar uses an ultra wideband frequency-modulated continuous wave (FMCW) waveform to obtain high range resolution. Our system is composed of a vertical linear array to discriminate targets in elevation and two transmit elements operated in a slow multiple-input multiple output (MIMO) configuration to increase the achievable elevation resolution. High resolution in the along-track direction is obtained through synthetic aperture radar techniques. We present experimental results that demonstrate the 3D capability of the radar. We further demonstrate target detection behind challenging walls, and imagery of internal wall features. Finally, we discuss future work.

8361-20, Session 5

Micro-Doppler processing for ultra-wideband radar

G. E. Smith, F. Ahmad, M. G. Amin, Villanova Univ. (United States)

Radar imaging of stationary objects behind walls and enclosed structures [1,2] proves to be a challenging task due to clutter. There are two approaches that allow clutter removal and wall mitigation [3,4]. The first employs change detection and predicates on re-imaging the scene at different times, followed by subtraction of the image values. This approach is a special case of a first-order delay-line canceller where the delay may involve a long period of time and numerous pulses. The second uses pulse-Doppler radar that allow separation of targets and clutter in the frequency domain. However, if human activity classification, based on limb movements, is to be employed signal processing beyond basic sub-band filters or the Fourier transform must be employed.

In this paper, we describe an operational pulse Doppler radar system for indoor target localization and classification, and show how a target's micro-Doppler signature (μDS) [1] can be processed when ultra-wideband (UWB) waveforms are employed. Unlike narrowband radars where time-frequency signal representations can be applied to reveal the target time-Doppler frequency signature, our system permits joint time-frequency analysis (JTFA) [5]. JTFA outputs the data in a domain representing range, frequency and time, allowing both the μDS and high range resolution (HRR) signatures to be observed.

Real data is used to demonstrate the effectiveness of UWB pulse-Doppler radar, combined with nonstationary signal analyses, in gaining valuable insights into human positioning and motions. It delineates the relationship between the μDS and the HRR signature, showing how they would form a complimentary joint feature for classification. The paper depicts the main components of our UWB pulse-Doppler radar system, which employs a novel fast-time sample reconstruction technique to allow sub-Nyquist sampling rates on the analogue-to-digital converters (ADCs). The system produces coherent images at a rate of 100Hz, which is sufficient for observing the μDS of human targets. Data showing the different JTFA of human targets will be presented, and the benefits of this new analysis method for UWB μDS discussed.

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8361-21, Session 5

Histogram-based segmentation for stationary indoor target detection

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The problem of stationary target detection in through-the-wall radar imaging and urban sensing using statistical detectors has recently been

considered in the literature [1-2]. Specifically, both conventional and adaptive techniques based on a pixel-wise Neyman-Pearson test were used to detect targets in indoor radar images. A shortcoming of these statistical detection techniques is that appropriate probability density functions of target and clutter need to be predefined. In most practical scenarios, this information is not available beforehand. In this paper, we apply image segmentation techniques, which have commonly been applied to SAR images [3-4], to radar images of scenes associated with urban sensing. For the specific data analyzed, it is shown that the nature of the targets and clutter in the image allows successful application of the histogram based thresholding image segmentation methods to distinguish between target and clutter regions. More specifically, the Otsu's method [5] and maximum entropy segmentation [6] are considered to aid in removing the clutter, resulting in 'clean' radar images with target regions only. Unlike the statistical detection methods, image segmentation techniques are nonparametric and, therefore, do not make any assumptions about the image statistics. However, image segmentation methods do not provide any control over the false-alarm rate and suffer from the problem of declaring segmented regions even in the absence of targets in the scene. The image segmentation schemes are applied to real-data collected using the Multi-channel TWSAR, which is the vehicle-borne through-the-wall radar imaging system by Defence Research and Development Canada (DRDC). The datasets correspond to free-space measurements of an aluminum coated sphere and trihedral corner reflectors, placed at different downranges and heights in an empty field. The vehicle remained stationary during the entire data collection experiments. The results obtained with the image segmentation techniques are compared to those obtained after statistical detection. Although the principles of segmentation and detection are different and serve disparate objectives, it was observed that the segmentation techniques outperform the statistical detector for the considered cases.

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8361-22, Session 5

A novel system for indoor situational awareness

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Based on the new "Through-the-wall radar" technology, the developed system allows to see through obstacles such as walls, doors and other visually opaque materials, covering a broad range of applications. The system is able to detect and locate survivors trapped inside a burning building or in areas which have been plagued by natural disasters (e.g. earthquakes, avalanches, dense smoke), and also to get an accurate overview of the inside of a building in e.g. a hostage crisis. People within the building can be detected and located.

In all these scenarios that demand entering unsafe buildings, interventions can represent a danger for firefighters, emergency relief workers and soldiers. Through-the-wall technology can improve situational awareness and reduce risks, before undertaking an intervention inside a structure. To this aim, SELEX Sistemi Integrati has developed an advanced solution able to meet requirements. Based on a consolidated expertise on inverse electromagnetic scattering, the solution is able to: estimate the thickness and the electromagnetic features of a wall; to estimate the internal layout of buildings, to detect vital signs and to track people movements inside buildings.

8361-23, Session 5

Evaluation of polarimetric through-the-wall radar measurements

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Fully polarimetric through-the-wall radar measurements with high spatial resolution have been attained by using the ISAR (Inverse Synthetic Aperture Radar) technique. Polarimetric methods have potential in this application since they may reduce the effects of the wall interaction and increase the contrast between humans and the background. This is especially the case with stationary target objects, where the highly sensitive Doppler technique is not applicable.

The main scene in the measurements was a human sitting in a small wooden cabin. The cabin was placed on a turntable and rotated, to obtain ISAR imaging. By switching between horizontal (H) and vertical (V) polarizations, four polarizations combinations were obtained. The central feature in this measurement was that phase coherence was maintained through a whole measurement series over the four combinations. This enabled co-processing of the whole collected data set with coherent methods. A statistical description of the measured data was used, with the coherency matrix applied to the received signals.

ISAR images produced for the TTW scenes show that the human can be discerned from the background. The contrast between the human and the background was found to be greater with vertical polarization at transmit and receive, with less contrast using cross-polarization or horizontal polarization, due to the horizontal wall grain orientation.

A classification scheme to discriminate between different target objects in the cabin has been tested. The method shows some promise, but a reliable classification has not yet been attained since the polarimetric features chosen in the scheme show some overlap.

8361-24, Session 6

High-efficiency switching power amplifiers for multiband radar

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The reduction of size, weight, power, and cost (SWaP-C) of radio frequency (RF) components is becoming increasingly important to meet industry requirements. In meeting the SWaP-C objectives, RF components will be required to be smaller and more power efficient than the current state- of- the- art while sustaining high performance functionality. In compliance with SWAaP-C and high performance functionality is a High Efficiency Switching Power Amplifier.

This study focuses on the more efficient breed of switching power amplifiers (PAs), particularly the Class F PA with new techniques to operate broadband on multiple radar bands. Efficiencies in the range of 60% to 80% for Class F PAs have been reported in the literature; however, this efficiency is only attainable over narrow bandwidths on the order of 10%.

Several innovative techniques have been identified to increase the efficiency and operational bandwidth of RF power amplifiers (PAs) for radar applications. The amplifier design also incorporates fast turn on and turn off circuits to achieve switching times of less than one microsecond (μs). This enables the PA to be switched off during switched off during the receive period to prevent self-generated noise from corrupting the received signal. Also, high-power transmit and receive (T/R) switches at the antenna feed can be eliminated.

A wideband PA enables the design of a multi-band radar, reducing the number of components needed for operation in the P, L, and X bands. A high efficiency PA is also key to reducing battery size and cooling requirements in radar applications.

8361-25, Session 6

Antenna array devised for amplifier integration

B. H. Strassner II, Sandia National Labs. (United States)

This presentation describes an active antenna array architecture designed specifically for achieving low transmit and receive sidelobe levels without using attenuators to create the necessary aperture taper. The emphasis here is on amplification and not on electronic beam steering. An “irregular” subarray approach is used to eliminate the need for attenuation within the array’s aperture, thereby reducing drastically the DC supply power consumption of the active phased array. On many UAVs, especially the smaller models, onboard DC power can be extremely limited. Large reductions in the array’s DC power consumption might allow for smaller UAVs to be used. The so-called “irregular” subarray approach not only determines the exact locations of the T/R modules, but it also allows for all of the low-noise amplifiers to share the same part number and for all of the power amplifiers to also share the same part number. In addition, all of the LNAs are biased exactly in the same manner as are all of the PAs. By keeping the part numbers and bias conditions of the amplifiers the same, large instantaneous operational bandwidths can be obtained. This is due to the fact that the amplifiers’ phase and magnitude profiles over frequency are the same assuming no part-to-part variations. Thus, this presentation illustrates an active antenna array topology that can achieve wideband performance and low sidelobe levels with minimal DC power consumption.

8361-26, Session 6

Compensating for inconsistent high-power vircator microwave radar pulse sources

A. D. McAulay, Lehigh Univ. (United States)

High power megajoule microwave pulses may be generated economically for radar by a vircator (virtual cathode oscillator, McAulay 2011 Wiley book [1]) . Vircators are often driven by a Marx generator that relies on spark gaps to discharge a bank of capacitors. Because of the inconsistency of spark gaps, and operation of the vircator, the resulting ringing vircator pulse has a different shape each time a pulse is generated. We seek to remove the effects of the ringing and pulse shape from the collected data. The high power allows vey long ranges, or combined with array processing it allows penetration farther into the ground (McAulay, this conference in 2011,SPIE 8021-1 [2]). By assuming that data is random for a given pulse and that the pulse is minimum phase (commonly arising for pulse sources) we can estimate the power spectrum from the data for a given pulse. The pulse amplitude and phase as a function of time is estimated by spectral factorization. This estimate of the pulse is used to deconvolve the effects of the pulse out of the data. The removal of pulse specific ringing shortens the pulse for higher range resolution and allows data from several pulses from a single vircator or different vircators to be combined for joint processing in a SAR. We describe the process in detail and discuss algorithms for a simulation prior to performing tests on real data.

[1] A. D. McAulay, A., D., Military Laser Technologies for Defense, Wiley, New York, (2011).

[2] A.D. McAulay, “Ground penetration radar using free-electron maser,” SPIE 8021-1 (April 2011)

8361-27, Session 6

Developments in extraordinary transmission metallic lens

M. Navarro-Cia, Imperial College London (United Kingdom); M. Beruete, F. Falcone, M. Sorolla, Univ. Pública de Navarra (Spain)

The notion of metamaterial engineering begins from the principle of homogenization. In metamaterials, the effective parameters are highly influenced by the type of sub-units which one can engineer. Thus, by meticulously designing the individual sub-units, we can then create “homogenized” materials with bulk “designer” properties. This indeed brings great flexibility and is such a powerful tool that the interest in this field has exploded in the last decade, and has find applications in many research areas such as lenses.

Recently, the field of metallic lenses has been revisited by employing stacked subwavelength hole arrays (fishnet-like metamaterial). It was shown that a parabolic lens founded on such multi-layer configuration and working at the frequency at which it emulates an effective medium with refractive index -1 could provide pencil-like radiation and potentially be free-space matched unlike classical metallic lenses.

In the quest to make this lens even more attractive, the response of this extraordinary transmission lens where it behaves like a near-zero index of refraction is investigated numerically and experimentally. We will show that by exploiting both regimes, dual-band capabilities are attainable. Moreover, a zoning technique is applied to the initial design to reduce the lens in terms of volume and weight. This well-known technique relies on removing passive parts of the lens where phase variation respect to free-space propagation is multiple of 2π. Because of the inherent narrowband response of the lens, this technique does not cause any penalty in its performance unlike it happen in classical lenses.

8361-28, Session 7

Image-based target detection with UWB OFDM radar with randomized sub-carrier assignment

T. Bufler, D. S. Garmatyuk, Miami Univ. (United States)

This paper proposes using the multi-spectral radar imaging methodology coupled with random sub-carrier weighting for target detection in complex scenarios. Multi-spectral imaging has been studied for infrared sensors, in which images corresponding to individual wavelengths can be analyzed via spectral decomposition. We propose to extend this concept to ultra-wideband (UWB) radar by means of employing multi-carrier waveforms based upon orthogonal frequency division multiplexing (OFDM) modulation. Individual sub-bands of an OFDM waveform can be processed separately to yield range and cross-range reconstruction of a target scene containing both useful targets and clutter. Random weights will be assigned to each sub-band to provide resistance to jamming and interference. Target detection in resultant images will be performed and contrasted with the detection performance of a traditional fixed-waveform SAR system using an automatic target detection algorithm. We hypothesize that by adaptive removal of clutter from these selected images, combined with random sub-carrier weighting we will attain better target detection performance in electronic countermeasure (ECM) scenarios. The graph below shows the preliminary results from our algorithm in which we examine the radar image by representing it as a vector field containing both clutter and target responses. The trend line of the vector magnitudes (vertical axis) will diminish with the number of samples if the target is present, but is expected to remain approximately constant if the image contains clutter only. Using this approach we perform image-based target detection.

8361-29, Session 7

A new phase space method for target discrimination

F. J. Rachford, T. L. Carroll, U.S. Naval Research Lab. (United States)

We have developed a method for radar/sonar target discrimination employing chaos or chaos like waveforms and a nearest neighbor cluster distance metric. We demonstrate this method by simulating radar scattering from four similar targets where the radar wavelength is on the order of the target size. We also study the accuracy and applicability of this method in the presence of added Gaussian noise and clutter. The four simulated targets employed were all approximately 4-5 wavelengths long by one wavelength in diameter and consisted of a right circular cylinder, an ogive, a cone-ogive and a 130 mm artillery shell. Waveforms were constructed by appending 1200 sinusoids with individual periods determined by an analog shift register chaotic map. This chaos-based radar pulse was made to have a center frequency of 2 GHz and 20% band width. Using a finite difference time domain code, we found the scattered mono-static return for each target over a 20° range of angles at 1° intervals. The scattered return waveforms were averaged over various angular windows and used to form references characteristic of the individual targets. Nearest neighbors selected from the target references and from the transmitted waveform were compared with the distribution of points at the reference indices of individual waveform returns for each target. We show a high probability of target discrimination even in the presence of large amplitude noise and spurious clutter.

8361-30, Session 7

Implementation of generalized detector for distributed sources using sensor arrays

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we consider the problem of detecting a random spatially distributed signal source by an array of sensors based on the generalized approach to signal processing in noise. We derive some generalized detector structures under several assumptions on the available statistics. The detection performance of these generalized detectors is evaluated and the effect of the angular spread of the source is investigated. We notice that the degrees of freedom of the distributions of the detection statistics depend on both the signal angular spread and the number of data snapshots. At high signal-to-noise ratio level and with small degrees of freedom, an increase of angular spread improves the detection performance. However, with large degrees of freedom, the increase of angular spread reduces detection performance. We provide a detailed discussion of the behavior of detection performance of the generalized detectors under various conditions. A comparison between the generalized detectors designed based on the generalized approach to signal processing in noise and the generalized likelihood ratio and conventional detectors is carried out by computer simulations. The results indicate a superiority of the generalized detectors constructed based on the generalized approach to signal processing in noise as the angular spread become large over the generalized likelihood ratio and conventional beamformer detectors.

8361-31, Session 7

Detection and depth estimation of shallow, buried non-metallic dummy landmines without explosives using independent component analysis of multipolarization data in microwave X band region

K. C. Tiwari, Bharati Vidyapeeth's College of Engineering (India); D. P. Singh, M. K. Arora, Indian Institute of Technology Roorkee (India)

A lot of research has been conducted with single polarization data obtained from different sensors with limited success. With the advent of satellites which can provide data in various polarizations, it has increasingly become relevant to investigate methods which can be used to manipulate data in different polarizations for the purpose of landmine detection. The conditions existing in the western borders of India match that of sandy deserts where surface roughness conditions are smooth making them extremely suitable for application of radar remote sensing for detection of minefields using data obtained in different polarisations. Independent component analysis (ICA) is an emerging signal processing technique which has been used to extract statistically independent signals from mixed signals. In this paper, application of Independent component analysis (ICA) for detection of dummy landmines (without explosives) using multipolarisation data has been investigated. The data for the purpose was generated through lab experiments in HH and VV polarizations in microwave X band frequency (10 GHz, 3 cm) using dummy landmines (without explosives). The backscatter data collected is cluttered due to several factors such as surface roughness and multilayer interactions etc. It was found that Otsu's thresholding when applied to ICA components obtained using FastICA algorithm provided good detections. The backscatter values obtained for the pixels segmented as landmine were further input in an EM (electromagnetic) model and optimized using a genetic algorithm based cost function for estimation of the depth. The model does not have any requirement of any a priori data and still highly accurate results.

8361-32, Session 7

Classification and modeling of human activities using empirical mode decomposition with S-band and millimeter-wave micro-Doppler radars

D. P. Fairchild, R. M. Narayanan, The Pennsylvania State Univ. (United States)

The ability to identify human movements can be an important tool in many different applications such as surveillance, military combat situations, search and rescue operations, and patient monitoring in hospitals. This information can provide soldiers, security personnel, and search and rescue workers with critical knowledge that can be used to potentially save lives and/or avoid a dangerous situation. Most research involving human activity recognition is focused on using the Short-Time Fourier Transform (STFT) as a method of analyzing the micro-Doppler signatures. Because of the time-frequency resolution limitations of the STFT and because Fourier transform-based methods are not well-suited for use with non-stationary and nonlinear signals, we have chosen a different approach. Empirical Mode Decomposition (EMD) has been shown to be a valuable time-frequency method for processing non-stationary and nonlinear data such as micro-Doppler signatures and readily provides a feature vector for classification. For classification, the method of a Support Vector Machine (SVMs) was chosen. SVMs have been widely used as a method of pattern recognition due to their ability to generalize well and also because of their moderately simple implementation. In this paper, we discuss the ability of these methods to accurately identify human movements based on the micro-Doppler signatures obtained from UHF, S-Band, and millimeter-wave radar systems. Comparisons will also be made based on experimental results from each of these radar systems. Furthermore, we will present simulations of micro-Doppler movements for stationary subjects that will enable us to compare our experimental Doppler data to what we would expect from an "ideal" movement.

8361-33, Session 8

Radar cross-section statistics of cultural clutter at Ku-band

A. M. Raynal, D. L. Bickel, A. W. Doerry, Sandia National Labs. (United States)

Knowing the statistical characteristics of the radar cross-section (RCS) of man-made, or cultural clutter, is crucial to the success of clutter mitigation, radar target detection algorithms, and radar system requirements in urban environments. Open literature studies regarding the statistical nature of cultural clutter focus primarily on radar probability models or limited experimental data analysis of specific locations and frequencies. This paper seeks to expand the existing body of work on cultural clutter RCS statistics at Ku-band for ground moving target indication and synthetic aperture radar applications. We examine the RCS probability distributions of cultural clutter in several urban scenes, across elevation angle, for HH and VV polarizations, and at diverse resolutions, using experimental data collected at Ku-band. We further describe frequency and RCS strength statistics of clutter discretes per unit area to understand system demands on radars operating in urban environments in this band.

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8361-34, Session 8

Radar micro-Doppler simulations of classification capability with frequency

D. Tahmoush, J. Silvious, U.S. Army Research Lab. (United States)

Extracting and understanding human signatures using radar requires a detailed understanding of the RF scattering phenomenology associated with humans as well as their motion. The gross translational Doppler signals associated with walking are well documented in the literature. We describe modeling procedures as well as supporting anechoic chamber and outdoor measurements of humans engaged in the signature activity of walking. We utilize motion capture data to animate models and provide human motion variants for classification. This work seeks to estimate the classification capability of the micro-Doppler signals generated by human motion as a function of the radar frequency and other parameters.

8361-35, Session 8

EM investigation on imaging of disturbed Earth feature for buried target detection

D. Liao, U.S. Army Research Lab. (United States)

Full-wave electromagnetic (EM) simulations from UHF to X-band are undertaken to investigate the feasibility of exploiting ground surface scattering for subsurface target detection. The ground surface containing a disturbance due to target emplacement is represented with a composite roughness profile characterized by Gaussian statistics, in conjunction with a homogeneous dielectric model. Preliminary bistatic, wideband imaging results derived from a forward-looking sensing configuration indicate that at X-band, for the parameters defined in this work, the disturbed surface feature is observable with a scattering distribution that is clearly distinct from that of the undisturbed surface. At lower frequencies (UHF to C-band), the disturbance is far less apparent due to the lack of sufficient image resolution. However, the target itself is visible at the lower frequencies-up to L-band for vv and to S-band for hh. In other words, for the relatively smooth surface studied, the radar return is primarily determined by the scattering component from the target at the lower frequency bands and from the rough surface at the higher frequency bands. It is surmised here that a fusion of the results from different bands can be used to enhance target detection. For example, as a complement to the UHF response, the X-band response can be employed to infer whether the target is on-surface or buried. Note that although the exact nature of the scattering effects of the ground is very much dependent upon the properties and statistics of the composite surface profile, the general observations made herein are expected to be applicable to the wider class of disturbed earth features encountered in practical radar sensing scenarios.

8361-36, Session 8

In-situ permittivity measurements using ring resonators

G. J. Mazzaro, U.S. Army Research Lab. (United States)

Proper development of ultra-wideband (UWB) ground-penetrating radar (GPR) technology requires a unique understanding of the electromagnetic (EM) properties of target and background deployments. Thus, electromagnetic characterization of targets and backgrounds is fundamental to the success or failure of UWB GPR as a threat detection technique.

In many cases, threats are buried in soil. Soil properties directly affect the radar signature of targets and determine the depth at which they can be detected by radar. One such property is permittivity. Permittivity indicates the transmission, reflection, and absorption of EM radiation by a dielectric material. It is an intrinsic material property that depends on temperature and water content; therefore, permittivity for sand, soil, and vegetation varies by location and time-of-day. Thus, to accurately model the behavior of radar pulses in a test environment, permittivity must be measured as near to the radar test area as possible. A portable system recently developed at the U.S. Army Research Laboratory measures permittivity in-situ with minimal disturbance of the dielectric sample. The measurement technique uses ring resonators.

Design equations and physical dimensions are presented for fabricating resonators at frequencies between 600 MHz and 2 GHz. Only a handheld vector network analyzer, coaxial cabling, and the ring resonators are necessary for each measurement. Lookup curves generated in simulation are referenced to calculate the complex permittivity of the sample. The permittivity measurement is explained, step-by-step, and data is presented for samples of soils from Yuma, AZ and Socorro, NM.

8361-47, Poster Session

A better trihedral corner reflector for low-grazing angles

A. W. Doerry, B. C. Brock, Sandia National Labs. (United States)

Trihedral corner reflectors are the preferred canonical target for SAR performance evaluation for many radar development programs. The conventional trihedrals have problems with substantially reduced Radar Cross Section (RCS) at low grazing angles, unless they are tilted forward, but in which case other problems arise. Consequently there is a need for better low grazing angle performance for trihedrals. This is facilitated by extending the bottom plate. A relevant analysis of RCS for an infinite ground plate is presented. Practical aspects are also discussed.

The genesis of this work was the need to develop better low grazing angle performance for canonical targets, those for which RCS can be relatively accurately calculated. Previous attempts to use conventional trihedrals tilted forward, sometimes on tripods, has offered ambiguous results, due to multipath phenomena. In addition, using conventional trihedrals with apex at ground level has led to RCS measurements exceeding the predicted free-space value, not surprisingly, due to ground-bounce. Consequently, the need became apparent to modify the conventional trihedral performance by altering its geometry to address these faults, and offer more predictable performance with greater RCS at low grazing angles.

8361-48, Poster Session

What maritime ISAR designers should know about ship dynamics

A. W. Doerry, Sandia National Labs. (United States)

Inverse Synthetic Aperture Radar (ISAR) is in fact a synthetic aperture imaging technique, but also allows that the target itself is moving, and often with unknown velocities, both linear and angular. It is a much more difficult problem than SAR due to the unknown motions. ISAR is also range-Doppler imaging, but the Doppler includes target motion, too.

ISAR has enjoyed some success in imaging maritime targets, in particular ships. In fact, a number of maritime ISAR systems have been operational for a number of years. Although operational and useful, such systems still typically lag the image quality of terrain imaging SAR. Operators of such system routinely refer to ISAR image analysis as "blobology". Nevertheless, system requirements that include a maritime ISAR mode are increasingly popular.

It is difficult to imagine accounting for ship motion without first understanding the nature of the ship motion we are likely to encounter. Designing ships for specific motion characteristics is the domain of naval architecture. This field enjoys a history as long as human's interest in building water craft. This field has a language all its own, and many empirical rules for predicting ship characteristics. Rules tend to be empirical because of the difficulty in achieving closed form solutions for highly non-linear phenomena in hydrodynamics.

This paper presents some preliminary analysis of naval architecture principles, and typical ship designs' impact on the ISAR problem.

8361-49, Poster Session

Designing interpolation kernels for SAR data resampling

A. W. Doerry, Sandia National Labs. (United States); E. Bishop, J. Miller, V. Horndt, General Atomics Aeronautical Systems, Inc. (United States); D. Small, Sandia National Labs. (United States)

It is fairly common in radar signal processing that sampled data is not sampled precisely at the desired positions within a function. Resampling the data to more advantageous sample locations entails interpolation of the data. The radar engineer often picks a resampling or an interpolation technique that "is handy", or "seems to work", without any analytical justification for his choice. However, understanding the science and mathematics that underpin interpolation can avoid unexpected and undesirable side effects from a suboptimal choice. This paper details interpolation kernel characteristics, allowing intelligent choices for algorithm design, tailored for radar signal processing applications.

8361-50, Poster Session

Multitarget detection algorithm for automotive FMCW radar

E. Hyun, J. Lee, Daegu Gyeongbuk Institute of Science & Technology (Korea, Republic of)

Recently, the radar driven automotive driver assistant systems are currently designed to increase comfort and safety. In radar systems, target range and velocity should be measured simultaneously with high accuracy, even in multi-target situations.

Almost all over world, FMCW(Frequency Modulation Continuous Wave) radar has been used as an effective method. But, FMCW radar possesses the ambiguities to separate ranges and velocities for each target with wide relative velocity and range, and identify the correct combinations of beat frequencies for multiple targets. These problems bring out so-called 'ghost targets' in range-velocity processing and it can reduce the radar detection performance.

In this paper, we propose the waveform and detection algorithm in order to overcome these limitations. The transmitted wave and detection algorithm is consists of two steps. In the first step, we detect coarse area in which there are targets using the detected frequency spectrum. In next step, the fine range and velocity of each target are extracted based on the results of first step.

The algorithms have been verified using simulation tool. This method improves the detection probability and reduces the false alarm rate of the FMCW radar. The next research step is a field test for real road and the enhancement of the detection algorithm.

8361-51, Poster Session

Tunnel monitoring with an advanced InSAR technique

B. Rabus, J. Eppler, J. Sharma, J. Busler, MacDonald, Dettwiler and Associates Ltd. (Canada)

The detection and monitoring of subsurface excavations such as tunnels and underground facilities has application in both the civil and defense domains. This includes monitoring of urban infrastructure development projects and subsurface mines and the detection of illicit tunnels in border regions and penal facilities.

Underground construction may result in surface deformation due to a combination of overburden relaxation and groundwater extraction. The measurement of this surface expression using InSAR (Interferometric SAR) is dependant on both the deformation pattern (magnitude and spatio-temporal characteristics) and the surface scattering properties. Often the surface expression is small and temporally transient and therefore requires advanced methods for effective detection and measurement of the deformation extent. We have developed a novel solution which combines both an adaptive spatial multilooking method with a matched spatio-temporal filter.

To achieve the high spatial resolution necessary to measure small, potentially one-dimensional underground structures we have developed a novel InSAR method (Homogenous Distributed Scatterer (HDS)-InSAR) that exploits both persistent point and coherent distributed scatterers by using adaptive multilooking of statistically homogenous pixel neighborhoods. Initial (unfiltered) deformation estimates have a noise level that is dependent on the coherence properties of the surface scatters. In order to enhance the detection of small scale structures in low SNR environments a matched parametric spatio-temporal model is fit to the deformation signal. We illustrate the performance of our new method by showing parametric detection results for the city of Vancouver over the last nine years using InSAR stacks of RADARSAT-1 and RADARSAT-2 data.

8361-53, Poster Session

Integrated radar-camera security system: range test

M. Zyczkowski, W. Ciurapinski, M. Szustakowski, M. Karol, Military Univ. of Technology (Poland)

The paper presents the test results of a mobile system for the protection of large-area objects, which consists of a radar and thermal and visual cameras. Radar is used for early detection and localization of an intruder and the cameras with narrow field of view are used for identification and tracking of a moving object. The range evaluation of an integrated system are presented as well as the probability of human detection as a function of the distance from radar-camera unit.

8361-56, Poster Session

Fast stereo matching under variable illumination

S. Arunagiri, E. Gallardo, A. Contreras, P. J. Teller, The Univ. of Texas at El Paso (United States); J. C. Deroba, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); L. H. Nguyen, D. R. Shires, S. J. Park, U.S. Army Research Lab. (United States)

Stereo matching is a technique of finding the disparity map or correspondence points between two images acquired from different sensor positions; it is a core process in stereoscopy. Automatic stereo processing, which involves stereo matching, is an important process in many applications including vision-based obstacle avoidance for unmanned air vehicles (UAVs), extraction of weak targets in clutter, and automatic target detection. Due to its high computational complexity, algorithms for stereo matching are one of the most heavily investigated topics in computer vision.

In this paper we introduce a fast version of an existing modern algorithm, the graph cut algorithm, and a new cost function based on zero mean cross correlation, which is expected to reduce errors in stereo images that do not satisfy the photo consistency property. We evaluate the effectiveness of the algorithm and the cost function for synthetic image pairs with different illumination intensities. The performance of the algorithm is evaluated in terms of execution time, the global minimum cost achieved, power and energy consumption, and the quality of the generated output. The results of this study establish the suitability and relative merit of the algorithm and cost function as a fast approximate solution for execution on field-deployable and on-board computer systems with size, weight, and power (SWaP) constraints.

This is an extension of an idea introduced in our paper presented at the same conference last year (2011). In the current study we use 14 optical stereo image pairs for which the ground truth data is available for evaluation of output quality. We use optical image pairs with differing illumination levels to simulate properties of images captured during different passes of an aircraft with on-board sensors.

8361-58, Poster Session

Novel nonlinear phase distortion estimation in wideband linear frequency modulated waveform using intermediate frequency signal

H. Yang, J. Chun, KAIST (Korea, Republic of); S. Song, Samsung Thales Co., Ltd. (Korea, Republic of)

Recently, auto target recognition (ATR) based on high resolution radar or synthetic aperture radar (SAR) has been under remarkable attention in various applications of homeland security and weapon detection. In this paper, to satisfy the resolution requirements for ATR, we propose a novel scheme to estimate the nonlinear phase distortion caused by the limit of VCO in wideband linear frequency modulated waveform (WLFMW) system digitally and the result can be exploited to compensate the distortion via predistortion. Our simulation results demonstrate that the proposed scheme has good estimation performance without any expensive instruments such as network analyzer and the compensated data has the fine resolution.

The proposed scheme is described as follows:

1. Generation of IF signals

After two delayed RF signals pass through the mixer, we can get two delayed IF signals.

2. Extraction of the difference between the desired nonlinear phase distortion and the delayed nonlinear phase distortion

We can obtain the difference from an IF signal using Hilbert transform. Repeat this processing with two delayed IF signals.

3. Data refinement

We can use low pass filtering to suppress the noise included in the difference between the phase distortions. (Additionally, in case of the interrupted waveform, the high frequency components of the difference between the phase distortions, originated from the periodic discontinuity are eliminated automatically through LPF).

4. Constructing a sparse linear equation and solving the equation in the least squares sense.

Exploiting the difference between the phase distortions, we can construct a sparse linear equation and find the solution effectively using an algorithm such as LSQR.

8361-59, Poster Session

Target detection in forward-looking radar

R. I. Innocenti, K. I. Ranney, L. H. Nguyen, U.S. Army Research Lab. (United States)

The objective of the present investigation is to use radar data to detect targets situated on or under a road surface, and, at the same time, minimize the number of false alarms. The data used here have been collected by the Army Research Laboratory (ARL) Synchronous Impulse Reconstruction (SIRE) Radar. These data have been processed at different ranges from the radar, at different depression angles, and with different resolution. This has been achieved by integrating the data collected during the forward motion of the radar along the road. As a result, it has been possible to produce a series of images of the road in front of the radar at progressively better resolution. We show how the exploitation of the different behavior of clutter and targets at different resolution allows higher rates of target detection at lower false alarm rate than otherwise possible.

8361-60, Poster Session

Contrast-based moving target detection with the randomized linear receive array

K. I. Ranney, A. F. Martone, R. I. Innocenti, L. H. Nguyen, U.S. Army Research Lab. (United States)

The Army Research Laboratory (ARL) has, in the past, demonstrated the effectiveness of low frequency, ultrawideband radar for detection of slow-moving targets located behind walls. While these initial results were promising, they also indicated that sidelobe artifacts produced by moving target indication (MTI) processing could pose serious problems. Such artifacts induced false alarms and necessitated the introduction of a tracker stage to eliminate them. Of course, the tracker algorithm was also imperfect, and it tended to pass any persistent, nearly collocated false alarms.

In this work we describe the incorporation of a sidelobe-reduction technique-the randomized linear receiver array (RA)-into our MTI processing chain. To perform this investigation, we leverage data collected by ARL's synchronous impulse reconstruction (SIRE) radar. We begin by calculating MTI imagery using both the non-random and randomized array methods. We then compare the sidelobe levels in each image and quantify the differences. Finally, we apply a local-contrast target detection algorithm based on constant false alarm rate (CFAR) principles, and we analyze probabilities of detection and false alarm for each MTI image.

8361-61, Poster Session

Multiresolution SAR image processing for forward-looking radar

L. Nguyen, K. I. Ranney, U.S. Army Research Lab. (United States)

No abstract available

8361-62, Poster Session

Persistent ISR using Predator B / MQ-9 Reaper demonstrating integration with Navy networks using surrogate platform

R. Dunkel, Z. Link, T. J. Verge, J. Laue, General Atomics Aeronautical Systems, Inc. (United States)

No abstract available

8361-63, Poster Session

An efficient means to mitigate wavefront curvature effects in polar format processed SAR imagery

R. Linnehan, M. Yasuda, General Atomics Aeronautical Systems, Inc. (United States); A. W. Doerry, Sandia National Labs. (United States)

The polar format algorithm (PFA) exploits the efficiency of fast Fourier transforms (FFT) to form SAR images by assuming a planar wavefront of the radar beam as it moves through the illuminated region. However, this approximation causes notable geometric distortions and defocusing of scattering responses in larger images where the spherical nature of the wavefronts becomes discernible. The degree of distortion increases with distance from the reference location used in the PFA processing, typically the image center. Misrepresentation of targets and terrain over large geographical regions can make real-time or forensic analysis of SAR imagery unnecessarily challenging.

We are developing a method to manage the effects of wavefront curvature on SAR images processed using the PFA for the Lynx Radar System built by General Atomics Aeronautical Systems, Inc. The complete, processed image is divided into sub-images and the translation property of the Fourier transform is utilized to compensate for spatial shifts and smearing of the pixels. After adjusting the phase and transforming the data back to the spatial domain, the sub-images are reassembled into a full image once again. Since the intensity of the correction increases with distance from the center, the sub-images are separated into progressively smaller sizes to minimize discontinuities that arise from the discrete nature of this post-processing technique. The result is a SAR image that has been created more efficiently than competing SAR processing methods that do not use the FFT in the azimuth dimension, without limitations on scene size due to wavefront curvature distortions.

8361-37, Session 9

Low-cost chaotic radar design

G. M. Hall, E. J. Holder, Propagation Research Associates, Inc. (United States); S. D. Cohen, D. J. Gauthier, Duke Univ. (United States)

An approach for creating a low-cost Chaos Pulse Doppler Radar is presented. The objective of this effort is to develop a practical realization of a Chaotic Radar with performance advantages over other approaches. Many groups [1,2,3] have proposed that Chaotic Waveforms are an effective radar signal generator due to: the relatively low-cost of producing complex wide-band waveforms and the difficulty in detecting and spoofing inherently complex modulations. PRA and Duke University report on the development of a radar design that uses a novel high-speed chaotic waveform generator. Experimental results are presented that characterize the performance of a chaotic waveform generator. A design of a receiver based on a chaos match filter will also be described. In addition, radar architecture will be proposed, realistic radar design criterion will be set forth and simulations of a complete radar will be used to compare the chaotic radar to more traditional radar approaches.

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8361-38, Session 9

Information retrieval and cross-correlation function analysis of random noise radar signal through dispersive media

A. V. Alejos, M. Dawood, New Mexico State Univ. (United States)

In this contribution we examine the propagation of an ultrawideband (UWB) random noise signal through dispersive media such as soil, vegetation, and water, using Fourier-based analysis. For such media, the propagated signal undergoes medium-specific impairments which degrade the received signal in a different way than the non-dispersive propagation media.

Theoretically, larger penetration depths into a dispersive medium can be achieved by identifying and detecting the precursors, thereby offering significantly better signal-to-noise ratio and enhanced imaging. For a random noise signal, well defined precursors in term of peak-amplitude do not occur. The phenomenon must therefore be studied in terms of energy evolution.

Additionally, the distortion undergone by the UWB random noise signal through a dispersive medium can introduce frequency-dependent uncertainty or noise in the received signal. This leads to larger degradation of the cross-correlation function (CCF), mainly in terms of sidelobe levels and main peak deformation, and consequently making the information retrieval difficult.

We further analyze various methods to restore the shape and carrier frequency of the input UWB random noise signal, thereby, improving the CCF estimation.

8361-40, Session 9

Analysis of the ambiguity function for an FM signal derived from the Lorenz chaotic flow

C. S. Pappu, B. C. Flores, The Univ. of Texas at El Paso (United States); P. S. Debroux, U.S. Army Research Lab. (United States)

In prior work, we showed that any one of the state variables of the Lorenz chaotic flow can be used effectively as the instantaneous frequency of an FM signal [1]. We further investigated a method to improve chaotic-wideband FM signals for high resolution radar applications by introducing a compression factor to the Lorenz flow equations and by varying two control parameters, namely ρ and β, to substantially increase the bandwidth of the signal [2]. In this paper, we obtain an empirical quadratic relationship between these two control parameters that yields a high Lyapunov exponent which allows the Lorenz flow to quickly diverge from its initial state. This, in turn, results in an FM signal that has an agile center frequency that is also chaotic. A time-frequency analysis of the FM signal shows that variable time-bandwidth products of the order of 105 and wide bandwidths of approximately 10 GHz are achievable over short segments of the signal. Next, we compute the average ambiguity function for a large number of short, equal-length segments of the signal with positive range-Doppler coupling. The resulting ambiguity surface is shaped as a set of mountain ridges that align with multiple range-Doppler coupling lines with low self-noise surrounding the peak response. Similar results are achieved for equal-length segments of the signal with negative range-Doppler coupling. The characteristics of the ambiguity surface are directly attributed to the frequency agility of the FM signal which could be potentially used to counteract electronic counter measures aimed at

traditional chirp radars.

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8361-41, Session 9

Detection performance of the LFM noise radar waveform

M. Govoni, U.S. Army Research, Development and Engineering Command (United States); J. Kosinski, Monmouth Univ. (United States)

We compare the sidelobe levels of the proposed waveform to the chirp and pure noise (stochastic) waveforms by evaluating the matched filter output for zero-delay when uniform, Hamming, Taylor, and triangular weighting functions are used. By measuring the sidelobe levels, we gain an understanding of (a) the power separation between the correlation peak and its first harmonic, and (b) the total power contained within the adjacent sidelobe structure.

The results from the sidelobe analysis are then used to determine the filter mismatch loss. This loss, in addition to the pulse duration and the channel noise figure, defines the radar scale factor (RSF) that is used during the probability of detection (Pd) analysis for the three waveforms. By scaling select signal-to-noise values by the normalized RSF, we identify what waveform has the maximum relative probability of detection when the number of time samples and weighting functions are varied. For our evaluation, we use 60,120,240,480, and 960 time-samples and a 10-6 probability of false alarm (Pfa) when uniform, Hamming, Taylor, and triangular weighting is used.

8361-42, Session 10

Noisy linear stepped frequency (NLSF) waveform in rf tomography

R. Vela, Univ. of Dayton Research Institute (United States); J. E. Bracken, L. Lo Monte, Air Force Research Lab. (United States)

Radio Frequency tomography has been proposed for imaging dielectric and conducting anomalies aboveground [1]. Accordingly, low-cost electromagnetic transmitters are placed arbitrarily above ground, surrounding a large area of interest. In a preliminary stage, sensors identify their position, orientation, and time reference. Subsequently, a transmitter radiates a known waveform. The probing wave impinges upon a target (represented in terms of the dielectric or conducting anomaly), thus producing scattered fields. Spatially distributed receivers collect samples of the total electric field, remove noise, clutter and the direct path, and store the information concerning only the scattered field. In the next iteration, a different transmitter is activated, or different waveforms are used. Then, the collected data is typically relayed to a centralized location for processing and imaging. To ensure persistent sensing, fast back-propagation algorithms are implemented (either involving correlation [2] or multiplication by a Hermitian matrix [1]). Resolution using back-propagation is affected by the sidelobe structure of the ambiguity function of the waveform. Clearly, Linearly Stepped Frequency (LSF) waveform requires the lowest instantaneous bandwidth but produces poor correlation properties [1]. On the converse, Noise waveforms exhibit the idealized thumb-tack ambiguity function but require large instantaneous bandwidths [2]. In an effort to exploit the benefits of both individual waveforms, a noisy LSF waveform is developed. The NLSF performance, limitation and spectral dominance in reference to RF Tomography, along with its theoretical bounds, will be provided. Reconstructed images from simulated and experimental data will be compared. *Submitted to Special Session on Noise Radar

8361-43, Session 10

Ultra-wideband noise radar based on optical waveform generation

D. Grodensky, D. Kravitz, A. Zadok, Bar-Ilan Univ. (Israel)

A microwave-photonic, ultra-wideband (UWB) noise radar system is proposed and demonstrated. The system brings together photonic generation of UWB waveforms and fiber-optic distribution. The use of UWB noise provides high ranging resolution and better immunity to interception and jamming. Antenna remoting over fibers allows for the separation the radar-operating personnel and equipment from the location of the front-end. The noise waveform is generated by the amplified spontaneous emission of erbium-doped fiber amplifiers. The noise bandwidth may be controlled through filtering by a fiber Bragg grating. The optical waveform is split in two: one replica is retained in a central office as a reference, and another is amplified and launched towards a front-end transmitter over an optical fiber. At the front end, the optical noise waveform is down-converted to the radio-frequency (RF) domain by a broadband detector. The RF noise is amplified and transmitted by one antenna, and reflections from targets at various distances are collected by a second, receiving antenna. The received waveform is used to modulate the output of a laser source, and is then transmitted back towards the central office over the same fiber. The received and reference waveforms are detected at the central office and cross-correlated, and the distances to the targets are recovered through the timing of cross-correlation peaks. Our experiments demonstrate a proof of concept for an integrated radar system, driven by optically generated 2 GHz-wide noise waveforms that are distributed over 10 km. Ranging resolution of 10 cm is obtained.

8361-44, Session 10

Impulse response characterization of the propagation and scattering environment in through-wall applications using an S-band noise radar

S. Smith, R. M. Narayanan, The Pennsylvania State Univ. (United States)

An ultrawideband (UWB) random noise radar operating at S-Band has been developed at the Pennsylvania State University for through-wall detection, ranging, tracking, and imaging of targets. The system transmits a bandlimited UWB noise signal and accomplishes detection by cross-correlating the reflected signal with a time-delayed replica of the transmit signal. Noise radars have been found eminently suitable for most though-wall radar applications. However, in such scenarios, the antennas and the barrier (i.e. the wall) cause distortions in the reflected signal due to their frequency-dependent radiation and loss characteristics, respectively. In this paper, we explore the feasibility of characterizing the impulse response of the antenna and various barriers using simulations and measurements using the S-Band noise radar. As is well known, the entire operation of a linear system (e.g., antenna or barrier) can be captured in its impulse response h(t), i.e. the output of the system when excited by an impulse function at its input, $\delta(t)$. Thus, impulse response testing provides a complete diagnosis of the system over its entire mode of operation. However, generating an ideal impulse function in time is quite difficult since realistic components have finite rise and fall times. While the power spectrum of the impulse is uniform from 0 to ∞, using a large enough bandwidth will suffice for testing purposes, as long as the bandwidth is much greater than the bandwidth of operation. It is here that noise waveforms are truly useful. Instead of using an impulse excitation, one can use a continuous noise waveform at the input whose constant power spectral density is $X(\omega) = Ni$, and measure the power spectrum at the output Y(ω). The transfer function of the system is therefore H(ω) = Y(ω)/X(ω) = Y(ω)/Ni. Once the transfer function is measured, the impulse response h(t) may be obtained by taking the inverse Fourier Transform of H(ω). Additionally, based on mathematical concepts developed by Yuk Wing Lee, it is also possible to ascertain the impulse response of a linear system whose input and output signals are white noise or noise-like via the cross correlation of the two signals. The advantage of using a noise waveform instead of a chirp waveform operating over the same bandwidth is that in the former, the frequency and amplitude vary randomly and arbitrarily with time, and thus provides a more demanding test environment for the system under analysis. Continuous noise waveforms are therefore ideal for testing frequency domain systems in place of conventional frequency-modulated chirp waveforms. This paper will present results on our impulse response characterization of the propagation and scattering environment. In addition, we will also present key concepts of noise radars, block-level architecture of our radar system, as well as some of the design and development of the helical (end-fire) antennas over short conical-shaped ground planes used by the system.

8361-45, Session 10

Simultaneous human detection and ranging using a millimeter-wave radar system transmitting wideband noise with an embedded tone

K. A. Gallagher, R. M. Narayanan, The Pennsylvania State Univ. (United States)

SUBMITTED TO SPECIAL SESSION ON NOISE RADAR:

This paper describes a millimeter-wave (mm-wave) radar system that has been constructed to simultaneously range and detect humans at distances of the order of several tens of meters. This is done by utilizing a composite signal consisting of two waveforms, a noise waveform and a single tone. These waveforms are summed together and transmitted simultaneously. Matched filtering of the received and transmitted noise signals is performed to range targets with high resolution, while the received single tone signal is used for Doppler analysis. The Doppler measurements are used to distinguish between human and non-human targets as well as to identify different human movements. Using hardware and software filters allows for simultaneous processing of both the noise and Doppler waveforms. Our measurements establish the mm-wave system's ability to detect targets up to and beyond 30 meters and also distinguish between human and non-human targets. Furthermore, our data shows discrimination of different human movements at distances up to and beyond 30 meters. In our paper, we will describe the architecture of the multi-modal mm-wave radar system and present results on human target ranging and Doppler characterization of human movements. In addition to detecting humans in a clutter free environment, the topic of foliage penetration is of current interest. This paper presents data for human detection through light foliage using the differences in the radar cross section (RCS) between light foliage with and without concealed humans. Data are also presented showing the difference in RCS between a human with and without a concealed metallic object.

8361-46, Session 10

Microwave noise fields: active radiometry principles and applications

J. G. Polivka, Spacek Labs. Inc. (United States)

The contribution presents the principles of Active Microwave Radiometry, noise radiators, radiometers, and antennas. The noise radiators generate the microwave noise field with a very low degree of coherence, and a radiometer system can evaluate its intensity (mapped in a surrounding space), its polarization and coherence.

Conference 8362: Passive and Active Millimeter-Wave Imaging XV

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8362-01, Session 1

Array technology for terahertz imaging

T. J. Reck, Jet Propulsion Lab. (United States)

Heterodyne terahertz (0.3 - 3THz) imaging systems are presently currently limited to single or low number of pixels. Drastic improvements in imaging sensitivity and speed can be achieved by replacing single pixel systems with an array of detectors. This paper presents the array topology based on the micromachining of silicon that is being developed at the Jet Propulsion Laboratory. Plasma etching of silicon is used to create the array's package and passive waveguide components. This process results in batch fabrication of devices with precision surpassing that of current metal machining techniques. This approach also increases the versatility of the packaging, enabling a variety of orientations of circuitry within the device, increasing circuit density and design options. Examples of this include a novel LO distribution network and power-divided multiplier circuits that were not feasible previously in metal-machined packages. In addition, the accuracy of the assembled packaged is addressed and new techniques are presented to improve alignment that will support higher frequency arrays.

8362-02, Session 1

Millimeter-wave, electronically scanned reflectarray optimization and analysis

A. Hedden, C. Dietlein, D. A. Wikner, U.S. Army Research Lab. (United States)

Applications including the detection of concealed explosives are driving the development of millimeter-wave technology capable of video-rate imaging of terrestrial scenes at standoff ranges near 50 m. Wafer-scale scanning reflectarrays and phased arrays offer important future prospects for implementing electronic beam scanning techniques with millimeter-wave imagers, thereby decreasing system weight, size, and complexity while improving robustness by eliminating mechanical scanners and associated hardware. In this work, we optimize and analyze wafer-scale two dimensional rectangular lattice arrays that could be used with a 220 GHz confocal imager. We explore trade-offs between quantization of phase states, array size, and scan angle error for common wafer sizes and phase shifters up to 3 bits. Resulting impacts on beam pointing accuracy and image resolution are gauged for our confocal camera geometry. In the interest of future fabrication feasibility, effects of element spacing including separations larger than /2 are considered. We also examine the effects of quantization lobes on imaging performance for confocal camera geometries.

8362-03, Session 1

Millimeter-wave beam forming and dynamic steering using an optically controlled photo-injected Fresnel zone plate antenna at 94GHz

T. F. Gallacher, D. A. Robertson, G. M. Smith, Univ. of St. Andrews (United Kingdom)

We present results for a rapid, precise and wide field-of-view scanning antenna for use at millimeter and sub-millimeter wavelengths, based on the photo-injected Fresnel zone plate antenna (PI-FZPA) method.

Our work demonstrates the potential of this technology as a viable solution to a range of applications demanding video rate imagery at these frequencies.

This technique is based on optically exciting free carriers in a semiconductor substrate, to form a plasma-based Fresnel zone plate antenna, which focuses and steers incident millimeter wave beams.

By reconfiguring the optically projected pattern, it is possible to dynamically, and rapidly, manipulate (sub-) millimeter wave beams within a 3D volume.

It is believed that the little attention devoted to this method since it was first demonstrated 20 years ago has been due to the high illumination densities required for sufficient plasma injection. Our work has made significant improvements in addressing this requirement and the technique is demonstrated using simple, commercially available hardware.

We present proof-of-principle experiments at 94GHz incorporating a commercial data projector. The 100mm PI-FZPA achieves 37dBi directivity, excellent beam symmetry, beam steering in two dimensions over a ±30° field-of-view, and precise beam control and repeatability at the 0.001° level.

Whilst current demonstrations are restricted to less than 20 beams per second with the current implementation, the technique is capable of achieving beam scanning rates of 10,000+ beams per second, suitable for video-rate imagery.

We also present, for the first time, results of a PI-FZPA integrated into a short range, 94GHz, 3D imaging radar.

8362-04, Session 1

Reflectarray for 120-GHz beam steering application: design, simulations, and measurements

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Development of a 120-GHz reflectarray is described. The reflectarray is realized on a 150-mm silicon wafer and it has 3700 phase-shifting elements on it. The phase shifters have four discrete values to cover full phase modulation with 90-degree steps. The reflectarray element is realized with a grounded coplanar waveguide patch antenna with a phase shifter coupled to it. The required phase shift for each reflectarray element is obtained with an in-house physical optics simulation combined with genetic-algorithm-based optimization. The reflectarrays are developed in two stages. First, preliminary reflectarrays with static phase shifters have been manufactured and tested at 120-GHz antenna measurement range. The static reflectarrays are found to perform as designed in their capability to steer the beam to a desired direction and to a distance of 3 m. The reflectarrays have -3 dB beam width of 0.9 degrees and 1.3 degrees at boresight and 9.5 degree beam tilt, respectively. The side lobe level and efficiency of the static arrays are also studied. After the preliminary verification with the static phase shifters, the reflectarrays will be assembled together with actively controlled MEMS-based phase shifters. First, the MEMS phase shifters are modeled, are being fabricated, and will be measured separately to verify their phase-shifting capability.

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8362-05, Session 2

340GHz 3D radar imaging test bed with 10Hz frame rate

D. A. Robertson, P. N. Marsh, D. R. Bolton, R. J. C. Middleton, R. I. Hunter, P. J. Speirs, D. G. Macfarlane, S. L. Cassidy, G. M. Smith, Univ. of St. Andrews (United Kingdom)

There is continuing worldwide interest in finding solutions to enhance the security of civilians at airports, borders and high risk public areas in ways which are safe, ethical and streamlined. One promising approach is to use sub-millimeter wave radar imaging to detect concealed threats.

We report on recent work adapting an existing 340GHz 3D imaging radar to provide a practical, field portable test bed suitable for data gathering and field trials targeting the above scenarios. The radar uses a wideband heterodyne scheme and fast-scanning optics to achieve few centimetre resolution volumetric data sets, over a ~0.5x0.5 m field of view, of targets at short stand-off ranges (~20 m) at a frame rate of 10 Hz.

At 340 GHz, quasi-optical techniques offer the best performance for signal manipulation and the radar uses custom-designed, state-of-the-art corrugated feedhorns, which achieve exceptionally low sidelobe, cross-polar and input return loss levels. A four-port quasi-optical duplexer based on a non-reciprocal polarisation rotating Faraday rotator provides transmit-receive separation with low insertion loss and high transmit-receive isolation, whilst maintaining high beam purity and low cross-polar levels. This is believed to the highest frequency radar to use a full four-port quasi-optical duplexer.

The use of DDS chirp generation, fast galvo scanners and efficient GPU-based data processing enables volumetric data to be acquired at a 10 Hz frame rate. This is sufficiently fast to follow smoothly the natural motion of people and allows the investigation of relevant image processing strategies.

8362-06, Session 2

Wide field-of-view millimeter-wave telescope design with ultra-low cross polarization

B. E. Bernacki, J. F. Kelly, D. M. Sheen, B. K. Hatchell, P. L. J. Valdez, J. R. Tedeschi, T. E. Hall, D. L. McMakin, Pacific Northwest National Lab. (United States)

As millimeter-wave arrays become available, off-axis imaging performance of the fore optics increases in importance due to the relatively large physical extent of the arrays. Typically, simple optical telescope designs are adapted to millimeter-wave imaging but single mirror spherical or conic designs cannot deliver adequate image quality except near the optical axis. Since many millimeter-wave designs are quasi-optical, optical ray tracing and commercial design software can be used to optimize designs to improve off-axis imaging as well as minimize polarization crosstalk. Methods that obey the Dragone-Mizuguchi condition for the design of reflective millimeter-wave telescopes with low cross polarization also provide additional degrees of freedom that offer larger fields-of-view than possible with single reflector designs. Dragone's graphical design method does not lend itself easily to computer-based optical design approaches, but subsequent authors expanded on Dragone's geometric design approach with analytic expressions that describe the location, shape, off-axis height and tilt of the telescope elements that satisfy Dragone's design rules and can be used as a starting point for computer-based design and optimization. We have designed and constructed a two-element unobscured F/4 reflective telescope design that exhibits a large field of view to accommodate millimeter-wave arrays described in the literature. In addition, the telescope was designed to have ultra-low polarization crosstalk (-58 dB) based upon the design approach first described by Dragone and Mizuguchi.

8362-07, Session 2

Stand-off, real-time, synthetic imaging at mm-wave frequencies

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We report on the development of an active stand-off imaging system operating in the 75 GHz - 110 GHz frequency range. 3D real-time imaging is enabled by a combination of a mechanically scanned one-dimensional conventional imaging projection with a rotating metallic reflector and a two-dimensional synthetic imaging reconstruction with a linear array of transmitters (Tx) and receiver (Rx) elements. The system is conceived, in order to allow a resolution better than 1cm both in lateral, as well as in range directions by using a multi-view imaging geometry with an aperture larger than 2 m x 2 m. The operation distance is 7,5 - 8,5 m. The 2D synthetically reconstructed imaging planes are derived from the correlation of 20 sources and 24 coherent detectors. Range information is obtained by operating in a FMCW (frequency modulated continuous wave) mode. Real-time imaging is enabled by implementing the synthetic image reconstruction algorithms on an embedded GPU (Graphical Processing Unit) system. The multi-view imaging geometry is implemented, in order to enhance the imaging resolution and to reduce the influence of specular reflections.

8362-08, Session 2

Measured performance of a high-resolution passive video-rate submillimeter-wave imaging system demonstrator for stand-off imaging

A. R. Luukanen, M. Grönholm, M. M. Leivo, H. Toivanen, A. Rautiainen, VTT Technical Research Ctr. of Finland (Finland)

In the paper we present the performance of our new 128 -channel submillimeter-wave camera, capable of cm-scale resolution at 5 m standoff system will be presented.

8362-09, Session 3

Polarimetric passive millimeter-wave imagery from a sensor based on an optical up-conversion architecture

J. Wilson, Univ. of Delaware (United States); C. A. Schuetz, T. E. Dillon, R. D. Martin, Phase Sensitive Innovations, Inc. (United States); D. W. Prather, Univ. of Delaware (United States)

Passive millimeter-wave (mmW) sensors are attracting a large amount of interest due to their ability to penetrate common atmospheric obscurants (such as fog and dust) and for their ability to operate regardless of day/night. These characteristics could allow for a sensor that can provide true persistent surveillance independent of weather conditions. Full-Stokes information can aid in target identification tasks and can also be used in the reduction of false alarms for explosives detection. Previous data collections at the Yuma Proving Grounds have shown that many objects exhibit unique polarimetric signatures due to the strong role reflections play in passive mmW phenomenology. It has also been shown that foam based IEDs exhibit a polarimetric signature at mmW wavelengths.

Current research is aimed at making a fully polarimetric passive millimeter-wave sensor based on an optical up-conversion design that can be scaled to a phased array design. The optical up-converison can potentially be used to realize a reduction in weight since optical

components can be used instead of bulky metallic RF components, for example, optical fibers instead of metallic rectangular waveguides.

This paper presents the latest results from this sensor including imagery of people and cars. The latest results from the full-Stokes sensor are presented and the performance of the system is discussed with an emphasis on the size, weight and power requirements and how they will affect future sensor design.

8362-10, Session 3

First results for a low-cost fast millimeter-wave radiometric imaging system

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For many military or peace-keeping operations it is necessary to provide better situational awareness to the commander of a vehicle with respect to possible threats in his local environment (predominantly ahead), at a distance of a few ten to a few hundred meters. Such a challenging task can only be addressed adequately by a suitable multi-sensor system. As a beneficial part of that, an imaging radiometer system with a sufficiently high frame rate and field of view is considered. The radiometer, working 24 hours in all weather and sight conditions, generates quasi-optical images simplifying the microwave image interpretation. Furthermore it offers the advantage to detect and localise objects and persons under nearly all atmospheric obstacles and also extents the surveillance capabilities behind non-metallic materials like clothing or thin walls and thin vegetation. Based on constraints of low costs and the observation of a large field of view, the radiometer still offers a moderate resolution at a moderate scan speed.

The paper describes the challenges for the design of a vehicle-based imaging radiometer system at W band, providing high-quality images of sufficient resolution for a large field of view at a moderate frame rate. The construction is outlined and first imaging results under nominal conditions are presented.

8362-11, Session 3

Real-time video rate imaging with a 1k-pixel THz CMOS focal-plane array

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We present the application of a fully-integrated 1k-pixel video-rate THz CMOS camera chip for security screening, industrial quality control, THz spectroscopy, and scientific and bio-medical solutions. The Si-lens integrated camera chip operates from 0.6-1THz at room temperature and is implemented in an industrial 65nm CMOS process technology. The 1k-pixel camera is capable of imaging at multiple frequencies over a wide bandwidth at the same time and at video rate, thus saving on imaging time, cost of multiple detectors and makes use of a low-cost technology suitable for mass production with high yield. The chip size is 2.9x2.9mm2 and each pixel is 80x80um2 large. The state-of-the-art Silicon designs [1-3] have only demonstrated single detectors requiring raster-scanning to produce THz images. This design demonstrates the first low cost, low power, large bandwidth, highly integrated, multipixel video-rate THz cameras suitable for hand-held real time imaging.

The active pixel topology consists of an on-chip ring-antenna, a differential resistive mixer, row/col decoders, as well as an integrate-and-dump circuitry. The THz resistive mixer core comprises of two differentially driven unbiased RF NMOS transistors. The detector operates beyond the transistors' fmax, and THz radiation is directly down-converted to DC through resistive self-mixing within the non-quasi-static channel of the NMOS [4].

The camera's operation was demonstrated by imaging moving point sources at 600GHz and 1THz looking from different directions. The camera works with an optical setup of lenses for imaging 1-kpixel video frames in transmission-mode of objects, at multiple spatial resolutions, and the video sequences are viewed in real-time.

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8362-12, Session 3

Flight test of MMW radar for brown-out helicopter landing

C. A. Martin, V. G. Kolinko, G. P. Otto, J. A. Lovberg, Trex Enterprises Corp. (United States)

No abstract available

8362-13, Session 4

Simulation of millimeter-wave body images and its application to biometric recognition

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Images acquired at the millimeter wave (MMW) band have unique properties that allow their application in many areas: security screening, non-destructive inspection, medical imaging and many more. Among them, a promising application is on biometrics. Biometrics based on this kind of images exploits the significant clothing transparency, health safety and low obtrusiveness of the MMW images, properties which are not present in images acquired at others spectral ranges.

However, due to the privacy concern of these images and the recent deployment of GHz imaging systems, there are no public available databases comprising human body MMW images. This fact hinders significantly the development of biometric systems based on this kind of images; in fact there is only one published research work that performs biometric recognition using a private database of MMW images. For all the above reasons, in this paper we describe a synthetic database called BIOGIGA. This database comprises 1200 synthetic images at 94 GHz of the body of 50 people. The generation of BIOGIGA has three stages: (i) acquisition of some corporal measures of each person, (ii) generation of corporal models (with and without clothing) from the former measures, using MakeHuman software, and (iii) simulation of the images at 94GHz, using Blender software, from each model in two types of scenes (outdoors and indoors) and with two types of imaging systems (passive and active).

Then, each of the resulting images is processed in order to extract a set of distance-based features. This process involves several steps: image segmentation, boundary extraction, landmark generation and feature vector construction. Third, among all the extracted features, the best subsets are selected using the SFFS feature selection algorithm. Finally these features are used in the final classification stage obtaining the final matching decision.

This paper will be structured as follows. The introduction and motivation

of the research will be introduced in Sect. 1. The generation, content and the main characteristics of BIOGIGA will be briefly presented in Sect. 2. Sect. 3 will describe the feature extraction process based on distance measures, and the selection of the best feature subsets. The experimental protocol, results and further discussion will be reported in Sect. 4. Conclusions will be finally drawn in Sect. 5 together with the future work.

8362-14, Session 4

Applicability of radio astronomy techniques to the processing and interpretation of aperture synthesis passive millimetre-wave applications

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A collaboration between the University of Manchester and QinetiQ is developing Passive Millimetre Wave Imagers (PMMWI) using the principles of interferometric aperture synthesis with the early introduction of digital signal processing. These are intended for use in a variety of applications, including personnel security screening, all-weather flight aids, and earth observation from a space platform. To enhance the cost-effectiveness of practical systems the number of collecting elements must be minimised whilst maintaining adequate image fidelity for a particular application. A wide range of techniques have been developed by the radio astronomy community for improving the fidelity of imagery produced by sparse interferometric arrays. However, the requirements of PMMWI applications in other areas can differ substantially in terms of image fidelity and dynamic range, coupled with the need for real-time processing and automated threat detection.

This paper discusses the applicability of various radio astronomy software techniques, in particular deconvolution and multi-frequency synthesis, to PMMWI applications. Experimental data from a proof-of-concept 32 element PMMWI system have been analysed with the same radio astronomy techniques to substantiate the results of the simulation programme. Realistic simulated targets include non-metallic objects concealed on persons; cables and other obstacles in all-weather air manoeuvres close to the ground.

8362-15, Session 4

Subwavelength resolution of MMW imaging systems using extremely inexpensive scanning glow discharge detector (GDD) double-row camera

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The properties of terahertz (THz) radiation are well known. They penetrate well most non-conducting media; there are no known biological hazards, and atmospheric attenuation and scattering is lower than visual and IR radiation. Thus THz imaging is very attractive for homeland security, biological, space, and industrial applications. In the other hand, the resolution of MMW images is lower comparing to IR and visual due to longer wavelength. Furthermore, the diffraction effects are more noticeable in THz and MMW imaging systems. Thus the MMW images are blurred and unclear and thus it is difficult to see the details and small objects. In recent experimental work with 8X8 Glow Discharge Detector (GDD) Focal Plane Array (FPA) we were able to improve the resolution of MMW images by using super resolution methods with simple DSP algorithms.

In this work a super resolution method with simple DSP algorithms will be demonstrated using the 2X18 double row camera. MMW images with sub wavelength resolution will be obtained using those methods and small details and small objects will be observed.

8362-16, Session 4

Automatic real-time concealed object detection and recognition with passive millimeter-wave imaging

S. Yeom, Daegu Univ. (Korea, Republic of); D. Lee, Daegu Univ. (United States); M. Lee, Y. Chang, Samsung Thales Co., Ltd. (Korea, Republic of); S. Jung, Samsung Thales Co., Ltd. (United States)

Millimeter wave can penetrate clothing to detect the concealed metal or man-made objects. Passive millimeter wave imaging has advantages to operate as a stand-off type sensor in both indoor and outdoor open spaces although it suffers from noise and environmental effects. Therefore, suitable image processing algorithms are required to enhance the capability of the system. In this paper, we discuss automatic real-time concealed object detection and recognition technique for passive millimeter wave images. The passive millimeter wave imaging system operates at 94 GHz, generating images with a 1 Hz frame rate. For detection, the concealed object is segmented by multi-level segmentation techniques. The multi-level segmentation technique comprises two stages: global and local segmentation. After the multi-level segmentation, the object region is extracted and processed by the matched filtering with based on the object models. The matched filtering is enhanced by the size and orientation-normalization stages for alignment. In the experiments, it will be shown that the proposed system can detect and recognize various objects with a good accuracy in real-time.

8362-17, Session 4

Evaluation of passive millimeter-wave system performance in adverse weather conditions

N. Gopalsami, S. Liao, A. Heifetz, E. R. Koehl, T. W. Elmer, Sr., A. P. C. Raptis, Argonne National Lab. (United States)

Passive millimeter wave (PMMW) imaging has shown distinct advantages for detection of materials under optically obscuring conditions such as through clouds, fog, and clothing. While the efficacy of the system for short-range detection of concealed materials in humans has been proven, more work is required in the quantitative determination of the system performance for terrestrial remote sensing in adverse weather conditions. The purpose of this paper is to establish operational limits of PMMW imager for target recognition with respect range of detection, frequency of operation, and climatic variables such as cloud, fog, and mist. To evaluate the system performance under controlled conditions, we have built an environmental chamber in which water droplets are introduced to create fog, and cloud, and mist of known quantities. The size and density distribution of droplets will be monitored by laser scattering instrumentation, as do the humidity and temperature in the chamber. We will present both theoretical results using radiative transfer theory and experimental verification of results with PMMW systems at two frequency bands, 70-100 GHz and 146-154 GHz. The data will be correlated with the environmental variables. These results will be useful for quantitative prediction of PMMW system performance for long-range terrestrial imaging.

8362-18, Session 4

Real-time computer treatment of THz passive device images with the high image quality

V. A. Trofimov, V. V. Trofimov, Lomonosov Moscow State Univ. (Russian Federation)

We demonstrate real-time operating computer code improving the quality of images captured by the passive THz imaging system. The code does not attach to certain THz passive device: it can be applied for both any kind of such devices and active THz imaging system as well. The perfomance of current version of the computer code is greater than 1 treatment per second for the THz image having more than 5000 pixel for 24 bit number representation. Single THz image results in about 20 images corresponding to various spatial filters applied for the image treatment. The computer code allows changing the number of pixels for resulting image without noticeable reduction of image quality. Functionality of the computer code is illustrated by its application to the treatment of images from a real THz passive imaging system.

We develop spatial filters which allow to see the samples with sizes being less than 2 cm. The performance of the computer code can be increased many times.

8362-19, Poster Session

Thermal human phantom for testing of millimeter-wave cameras

N. Palka, R. Ryniec, M. Piszczek, M. Szustakowski, M. Zyczkowski, M. Kowalski, Military Univ. of Technology (Poland)

Screening cameras working in millimetre band gain more interest among security society mainly because of their capability of finding hidden under clothes items. Performance of commercially available passive cameras is still limited due to poor resolution and contrast in comparison to other wavelengths (visible or infrared range). Testing of such cameras usually requires some persons carrying guns, bombs or knives. Such persons can have different clothes or body temperature, what makes the measurements even more ambiguous. To avoid such situations we built a moving phantom of human body. The phantom consists of a polystyrene manikin which is covered with a number of small pipes with water. Pipes were next coated with a silicon “skin”. The veins (pipes) are filled with water heated up to 37 C degrees to obtain the same temperature as human body. The phantom is made of non-metallic materials and is placed on a moving wirelessly-controlled platform with four wheels. The phantom can be worn with a set of ordinary clothes and can be equipped with some dangerous (guns, bombs) and non-dangerous (wallet) items. For tests we used passive commercially available camera TS4000 from Thruvison working at 250 GHz. Firstly, we compared the images taken for phantom and some persons and we obtained good similarity both for naked as well as dressed person/phantom case. We also tested phantom with different sets of clothes and hidden items and we got good conformity with persons.

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8363-01, Session 1

High-resolution reflection measurements of dielectrics in the w-band (92-100 GHz)

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A high resolution high power W-band (92-100 GHz) spectroscopic system was constructed and experimentally tested. The system is based upon two parabolic mirrors, two diagonal mirrors, a high power high resolution continuous wave tunable W-band source, and a unique detector. The spectrometer is fully computerized. The quasi-optical system was designed to transfer maximum beam power with minimum aberrations and minimum internal reflections. Stray refractions were eliminated by placing absorber blocks around the system. Spectral resolution of tens of kHz is achievable. The system was designed to measure transmission and specular reflection functions of dielectrics using a wide collimated beam of 75 mm diameter in order to simulate W-band imaging situations.

Within the framework of this work we will present specula reflection function measurements of different dielectrics including refractions from soil and water in W- band. Specular reflection functions of dielectrics for different incident angles will be presented as well.

8363-02, Session 1

Evaluation of terahertz spectra using chemometric methods

J. Jonuscheit, G. Torosyan, F. Ellrich, S. Wohnsiedler, M. Herrmann, R. Beigang, Fraunhofer-Institut für Physikalische Messtechnik (Germany); F. Platte, K. Nalpantidis, IANUS Simulation GmbH (Germany); M. Heise, Fachhochschule Südwestfalen (Germany); T. Sprenger, H. Wolf, Hübner GmbH (Germany)

For most publications, the samples have been measured under optimal conditions for recording undistorted spectra. However, in real-world applications the spectra are additionally influenced by several factors, e.g., water vapor lines, the roughness of the sample surface or covering. Hence, a reliable method for the automatic identification of substances from routine spectra has to be developed. Our approach is the use of chemometric methods for the extraction of information from THz measurements. In principle, similar methods are known from the evaluation of IR-spectra, but they have to be adapted to the specific features of broadband THz spectra. In most cases, the substance-specific information is hidden under the various environmental contributions to the THz spectra. It is essential to apply appropriate mathematical algorithms to pre-process the raw spectral data before a classificator is derived. Using raw data only would lead to unacceptably large values of "false positives" and "false negatives". We demonstrate that the data pre-processing (pipeline of filters) is essential for the discrimination of the measurements within the so-called "feature space". Based on a reliable and robust mathematical model, methods of pattern recognition can be used for automatic identification of substances. We also demonstrate that data derived from measurements in the reflection mode demand a much higher effort than for those recorded in transmission mode.

The identification performance is demonstrated using a spectrometer which is used to inspect mail. The substances to be identified were uncovered and covered by various postal envelopes.

8363-03, Session 1

Resonance structure of molecular clusters of -HMX for THz frequencies

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THz excitations are characteristically slow molecular states, in contrast to excitations that can induce electronic state transitions. Owing to the perturbative character of THz excitations, detection methodologies can be developed which do not damage materials. In addition, the perturbative character of THz excitation has significant implications with respect to its simulation using density functional theory (DFT).

A significant aspect of using response spectra calculated by DFT, for the direct construction of dielectric response functions, is that it adopts the perspective of computational physics, according to which a numerical simulation represents another source of "experimental" data. A general procedure may be developed for construction of dielectric response functions using DFT calculations as quantitative estimates of spectral response features for subsequent adjustment with respect to additional information such as experimental measurements and theory based calculations. DFT has been successfully applied to investigate response spectra of single molecules and molecular crystals.

Molecular clusters a characterized by a separate regime for dielectric response. The response spectra of molecular clusters provide a useful insight relating to the transition of a system from a single molecule to crystal. Presented are DFT calculations of ground state resonance structure of molecular clusters of beta-HMX. These are the ground state molecular geometries and response spectra for molecular clusters. These spectra are used to construct parameterized permittivity functions.

8363-04, Session 1

Integrated phase control on a portable coherent frequency-domain THz spectrometer

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Continuous wave frequency domain terahertz spectrometers that employ coherent detection are useful as portable tools since they typically may be operated at single frequencies or through large bandwidths, do not rely upon expensive components for construction, are capable of relatively high spectral resolution, and, most importantly, do not require consumables such as liquid helium. Interpreting the spectrum from a system that employs coherent detection can be challenging, however, due to the presence of an interference pattern. We report on the development of a portable, battery-operated frequency domain terahertz spectrometer with an integrated, fiber-coupled, lithium-niobate optical phase-modulator that permits the control of the terahertz phase, thereby allowing the control and removal of the interference pattern. The implications for both transmission and reflection measurements are discussed and data on the explosive compound RDX will be presented.

8363-05, Session 1

Terahertz properties of single-crystal ferroelectric and dielectric materials

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Frequency dependence of complex permittivity of selected ferroelectric and dielectric single crystals and ceramics has been measured in the terahertz (THz) region using time-domain THz spectroscopy. This has been accomplished by measuring transmittance through the samples over a broad range of about 300 GHz to about 4THz in our laboratory. Samples include crystals of BaTiO3, SrTiO3, LiNbO3, LiTaO3, LaAlO3, and Bi4Ge3O12 and a polycrystalline ceramics of (PbMg1/3Nb2/3O3)0.73-(PbTiO3)0.27. We have compared our results with millimeter wave (MMW), RF, microwave, and optical frequency permittivities of these materials. Effects of crystallographic orientations on the dielectric properties have also been examined. Our results demonstrate that dielectric properties of these materials in the THz region correlate well with data obtained in other spectral regions, thereby expanding available data to a wider range of the electromagnetic spectrum.

8363-06, Session 2

THz detectors based on heating of two-dimensional electron gas in disordered nitride heterostructures

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Two-dimensional electron gas (2DEG) in semiconductor heterostructures was identified as a promising medium for heterodyne mixing in early 90s. Up until now the only material, which has been pursued is AlGaAs/GaAs heterostructures. However, it is currently well understood, that parameters of 2DEG in AlGaAs/GaAs, such as high mobility and low carrier concentration, do not allow for achieving of a reasonable coupling to radiation above 1THz. We investigate possibilities of disordered GaN heterostructures for direct and heterodyne detection and for THz spectroscopy above 1THz. Here we present results on design, fabrication, and characterization of room-temperature hot-electron THz micro- and nanobolometers with ultra-low electron heat capacity. Several methods for 2DEG nanoscale patterning, including the split-gate design, are studied to fabricate sensors with ultrasmall electron heat capacity. We have experimentally demonstrated strong coupling of 2DEG to THz radiation due to the Drude absorption. Optimizing doping and geometrical parameters we reach 10-100 Ω detector impedances, which allow us to combine our sensors with available THz antennas. We clearly identify the mechanism of the 2DEG response to THz radiation as heating and currently specify its parameters. Measurements of mixing at sub-terahertz frequencies show that the mixing bandwidth is above 3 GHz, so the characteristic electron relaxation time is shorter than 50ps. Because of the ultra-low electron heat capacity of the sensor, the THz receiver will require the local oscillator (LO) power at the level of 1-10 μW. With such sensors, a single chain of THz frequency multipliers can be used to provide LOs to entire array of sensors.

8363-07, Session 2

Kinetics and dynamics of soldier protective materials via real-time terahertz scanning reflectometry

A. Rahman, Applied Research & Photonics, Inc. (United States); M. A. Mentzer, U.S. Army Aberdeen Test Ctr. (United States)

Development of Soldier personal protective equipment requires many delicate and precise characterizations to arrive at improved functionalities. This is an ever challenging task, requiring measurement of dynamic characteristics due to ballistic deformation. Among the most crucial parameters of a ballistic impact event are the kinetics of deformation and loss of material during the impact event. Current ballistic deformation characterization technologies are limited in their ability to provide adequate measurements of these parameters. A high sensitivity terahertz scanning reflectometer was used to characterize surface deformation characteristics in real-time (in-situ). Real-time measurements may also capture ballistic deformation kinetics of layered materials revealing behavior or constituent layers and their delamination during the impact. In addition, for non-metallic substrates, a transmitted beam may be used to capture loss of material of laminate layers due to impact. This parameter is important for computing kinetic energy of impact in real time. For the present work, deformation kinetics of composite layers of a helmet will be measured. A simulated ballistic impactor is used to strike the helmet with a pendulum, and the ballistic kinetics is captured at a high speed. Reflectance kinetics is converted to deformation depth and propagation speed is calculated from the kinetics spectrum. This technique also yields information about the post-impact relaxation behavior of the composite. Some details of the technique with exemplary results will be reported.

8363-08, Session 2

Tunable THz absorption using Al/SiO2 planar periodic structures

F. Alves, B. Kearney, D. Grbovic, G. Karunasiri, Naval Postgraduate School (United States)

THz imaging has been demonstrated using conventional, uncooled microbolometer-based imagers optimized for infrared (IR) wavelengths (8-12 μm) paired with external illumination provided by a QCL. To increase the sensitivity of these imagers, it is necessary to modify the pixel membrane structure to become a high THz absorbing layer, without compromising the thermal proprieties of the sensors. In this work, the design, fabrication, and characterization of relatively thin (less than 2 μm) THz absorbing structures (metafilms) with resonant absorption that can be tuned to the QCL illuminator frequency will be presented. The metafilms are comprised of periodic arrays of aluminum (Al) squares and an Al ground plane separated by a thin SiO2 dielectric film. Finite element simulations were performed by varying the structural parameters to establish the design criteria for high absorption, spectral tunability and bandwidth. Several structures were fabricated, and their absorption characteristics were measured. Nearly 100% absorption, multi- and broad- band absorption has been obtained in good agreement with that of the simulations. The favorable combination of thermal, mechanical, and optical properties of SiO2 and Al in addition to the flexibility of the square-mesh design make the proposed configuration highly suitable to improve the sensitivity of uncooled THz sensors.

8363-09, Session 3

Proposal for real-time terahertz imaging system with palm-size terahertz camera and compact quantum cascade laser

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M. Lee, LongWave Photonics LLC (United States); Q. Hu, Massachusetts Institute of Technology (United States)

This paper describes a real-time terahertz (THz) imaging system, using the combination of a palm-size THz camera with a compact quantum cascade laser (QCL). The THz camera contains 320x240 microbolometer focal plane array (FPA) with pixel pitch of 23.5 µm, which has quite flat spectral response in a frequency range of ca. 2 to 100 THz, and operates at 30 Hz frame rate. Noise equivalent power of THz-FPA itself is measured to be 20 - 40 pW in the frequency range mentioned above. The optics of the THz camera consists of two silicon lenses which are coated with Parylene. The optics can be equipped with infrared blocking filter. QCL is installed in compact Stirling cycle cooler and is operated at ca. 50K. A variety of QCLs (pulsed or continuous wave operations) are prepared which can cover frequency range from ca. 1.5 to 5 THz. High pulsed peak power levels larger than 1 mW at all frequencies and larger than 100 mW at selected frequencies are available. Duty cycle for the pulsed operation (pulse width : 200 nsec) is typically 2 %, which provides time average power of ca. 20 µW to 2 mW. THz images of biochemical samples will be presented, using the combined imaging system. Performance of the imaging system, such as signal-to-noise ratio, is predicted to be a couple of tens to hundreds, in the case that sample area of 1 cm in diameter is uniformly irradiated with QCL and is imaged on a part of THz-FPA (240 pixels in diameter).

8363-10, Session 3

Catadioptric optics for a high-resolution terahertz imager

N. Blanchard, L. Marchese, A. L. Martel, M. Terroux, É. Savard, C. Chevalier, L. Mercier, L. Gagnon, J. Lambert, M. Bolduc, A. Bergeron, INO (Canada)

In the past, INO developed infrared camera systems with microscanning capabilities to increase image resolution. INO has also shown in previous work that the image quality could be improved even if the pixel pitch is smaller than the point spread function.

This paper presents a catadioptric optics system with fully integrated microscan. The design, inspired by INO's HRXCAM infrared camera and adapted for terahertz wavelengths is made of two mirrors and one refractive element. It has a 11.9 degree full field of view and an effective F-number of 1.05 over a spectral range from 100µm to 1.5mm. This diffraction limited optics provides instantaneous high quality terahertz images. A THz camera, with its 160 x 120 pixels and 52 µm pitch combined with the microscan provides a 320 x 240 pixel image with 26 µm effective pixel pitch.

Microscanned images taken with the camera under an illumination at 118 µm are compared with the same image without microscanning.

8363-11, Session 3

Uncooled photomechanical terahertz imagers

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Security, process control, and military applications can immensely benefit from an uncooled, real-time THz imager that is low in cost with low size, weight, and power (SWAP). To meet these requirements, we have designed, built, and tested an uncooled THz imager based on optical readout photomechanical imaging technology, in which a MEMS-based sensor chip transduces the THz scene into a visible signal that is captured by a CCD imager. The performance of the 130×90 resolution, 100 µm pitch, 30 fps uncooled THz imager was measured using the λ = 119 µm (2.52 THz) emission line of a CO_2-pumped methanol gas laser. Excellent linearity of the responsivity was observed over a wide range of laser power. The noise equivalent power (NEP), limited by shot noise from the optical readout, was 76 pW/Hz^1/2. Switching to a high-capacity CCD imager to reduce shot noise and tailoring the photomechanical pixel structure for THz absorption will yield an NEP of less than 1 pW/Hz^1/2. In addition, the uncooled THz imager successfully profiled the output beam of a λ = 134 µm (2.24 THz) quantum cascade laser (QCL) in real time, with performance far superior to a commercial pyroelectric array camera.

8363-12, Session 3

Real-time imaging with THz fully customized uncooled amorphous-silicon microbolometer focal plane arrays

F. Simoens, Commissariat à l'Énergie Atomique (France); J. Meilhan, Commissariat à l'Energie Atomique (France)

Terahertz uncooled antenna-coupled microbolometer focal plane arrays are being developed at CEA-LETI for THz imaging and sensing. This detector technology relies on amorphous silicon bolometer know-how and aims at opening the way to real-time video rate 2D imaging, with potential low cost either in fabrication (Si technology) and in operation (no cooling). First prototypes of 320x240 pixel arrays have been designed for 1-3THz sensing in the 2 polarizations. Sensors have been fabricated monolithically above CMOS Integrated Circuits while applying only full Si standard silicon processes. High sensitivity and broadband spectral absorption have been characterized. After tests of imaging in reflection configuration presented at the last conference, we report lastest real-time reflectance 2D imaging tests that are performed with active illumination by Quantum Cascade Lasers.

8363-13, Session 3

A 3D THz image processing methodology for a fully integrated, semi-automatic and near real-time operational system

A. Brook, E. Cristofani, M. Vandewal, Royal Belgian Military Academy (Belgium)

Recently, there has been a significant interest in employing terahertz (THz) imagery for many industrial oriented and security applications. The main motivations for using this technology are: it allows penetration of most non-metal and non-polarized materials, it provides the ability for three-dimensional (3-D) imagery and in-depth information, and the THz waves pose no health risk to the operator. Given the high amount of information available in the THz images, appropriate image processing is of uttermost importance.

The present study proposes a fully integrated, semi-automatic and near real-time mode-operated image processing methodology developed for Frequency-Modulated Continuous-Wave (FMCW) THz images with the center frequencies around: 100 GHz, 300 GHz and 850 GHz. The quality control of aeronautics composite multi-layered materials and structures (e.g. solid laminates using fiberglass, sandwich structures containing Rohacell or honeycomb, etc.) using Non-Destructive Testing is the main focus of this work.

Image processing is applied on the reconstructed 3-D THz images to extract useful information. The proposed methodology firstly foresees to pre-process data by correcting any corrupted or non-uniform background, enhancing and de-blurring images. The data is subsequently processed by extracting areas of interest applying morphology operators, textural tools and edge detectors. Then, the detected areas are subjected to a dedicated image managed by the Markov random field method implementing a Bayesian approach. The contribution of using an integrated 3-D data set will be evaluated at this stage. Finally, the post-processing phase examines and evaluates the spatial accuracy of the extracted information by comparing image localization and dimensionality.

8363-14, Session 4

Recent progress on diode-based sources above 2 THz

T. W. Crowe, J. L. Hesler, S. Rezloff, G. Schoenthal, Virginia Diodes, Inc. (United States)

Recent progress in semiconductor manufacturing, circuit simulation, micro-assembly and power combining techniques are improving the performance of terahertz sources based on frequency multiplier diodes beyond what was previously thought possible. Two research groups have now demonstrated high quality sources for use in the 2.5-2.7THz frequency band for radio astronomy and chemical spectroscopy. These sources are frequency tunable and have excellent line quality. The power level is in the 1-5 microwatt range, which is sufficient for laboratory spectroscopy. The power is also sufficient to fully pump HEB mixers. In fact the sources developed at VDI have already been flown on the Stratospheric Observatory for Infrared Astronomy (SOFIA). This paper will review the design and performance of sources for this frequency band, and the prospects for improved power level and operating frequency as the technology continues to advance.

8363-15, Session 4

An open-path terahertz propagation test range for model-development validation

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The overall goal of the Terahertz Atmospheric and Ionospheric Propagation, Absorption and Scattering (TAIPAS) project is to develop a model relevant for atmospheric propagation and remote sensing in the range of ~1-3000 GHz, along with designing a THz propagation range suitable for evaluation of several critical aspects of SMMW propagation that have heretofore never been tested in field studies. Specifically, TAIPAS has focused on: 1) the design of a baseline 325-340 GHz phase coherent transmissometer system to extend the measurements performed during the 1983 Flatville near-millimeter wave (NMMW, 100-1000 GHz) field studies to higher SMMW/THz frequencies (~300-1000 GHz) in open path conditions, and 2) the integration of existing propagation models for absorption, refraction, and beam scintillation into a common modeling framework useful for image generation and link analysis from 1 to 1000 GHz. The transmitter is being located on the University of Colorado (CU) Center for Environmental Technology (CET) rooftop observatory on the CU Boulder campus, as seen in Figures 2-3. Two phase coherent receivers, spaced up to ~8 m apart are being built to enable measurement of the mutual coherence function. These receivers will be located at the NIST/NTIA Green Mesa site approximately 1.78 km from the transmitter site along a nearly level line of site path. The receiver site is provided by NTIA, which supports this work as a means of improving the scientific understanding of SMMW/THz propagation. Timing for coherency is achieved through a line-of-site C-band radar link. Initial results of the experiment will be presented here.

8363-16, Session 4

Design optimization of low-loss waveguides for THz guidance

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Although THz technology is emerging strongly, however, most of the present systems are free space based due to lack of low-loss waveguides. At this frequency range both dielectric and conductive losses of materials are high to design any suitable low-loss waveguides. Recently, it has been shown that hollow-core metal clad waveguides [1,2] can support THz waves in the low-loss air-core. It is also shown that by optimizing a dielectric layer between the air-core and metal layer, waveguide loss can be minimised. Similarly, it has also been reported that photonic crystal fibres with many hollow air-holes can confine most of the power in the low-loss air region to reduce the overall propagation losses. The development of low-loss THz guides is expected to provide impetus on the development of compact THz integrated circuits combining various functional devices.

Design optimization of such low-loss THz waveguides will be presented by using rigorous full vectorial finite element based numerical approaches.

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[2] B. M. A. Rahman, Anita Quadir, Huda Tanvir, and K. T. V. Grattan, “Characterization of plasmonic modes in a low-loss dielectric coated hollow core rectangular waveguide at terahertz frequency”, Accepted for publication in IEEE Photonics Journal.

8363-17, Session 5

Recent advances in room temperature semiconductor terahertz sources

M. Razeghi, Northwestern Univ. (United States)

The terahertz (THz) spectral range offers promising applications in science, industry, and military. THz penetration through nonconductors (fabrics, wood, plastic) enables a more efficient way of performing security checks (for example at airports), as illegal drugs and explosives could be detected. Being a non-ionizing radiation, THz radiation is environment-friendly enabling a safer analysis environment than conventional X-ray based techniques. However, the lack of a compact room temperature THz laser source greatly hinders mass deployment of THz systems in security check points and medical centers.

In the past decade, tremendous development has been made in THz Quantum Cascade Laser (QCLs), however, room temperature operation is still lacking mainly due to rapidly increasing LO-phonon scattering rate. Alternatively, recent demonstration of InP based mid-infrared QCLs with unprecedented performances at room temperature opens up the possibility of producing high power THz emission with difference frequency generation (DFB) through two mid-infrared wavelengths.

Given a much larger LO-phonon energy, III-Nitrides are also promising candidates for room temperature THz lasers. However, realizing high quality material for GaN-based intersubband devices presents a significant challenge. Advances with this approach will be presented.

8363-18, Session 6

Design, simulation, and characterization of THz metamaterial absorber

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In recent years a great amount of research has been focused on metamaterials, initially for fabrication of left-handed materials for use in devices such as superlenses or electromagnetic cloaking. Such devices have been developed and demonstrated in regimes from the radio frequency all the way to infrared and near optical frequencies. More recently, it has been shown that, by careful adjustment of the effective permittivity and permeability, near perfect electromagnetic absorbers can be realized. High absorption occurs when transmission and reflection are simultaneously minimized. With some clever tuning of the electric and magnetic responses, the electric and magnetic energy can therefore both be absorbed by the same metamaterial structure.

In this work we present the design, simulation and characterization of a novel thin, flexible, polarization insensitive metamaterial absorber. Finite-element simulation results show that this device achieves almost perfect absorption at THz frequencies. Each unit cell of the absorber is made up of two metallic structures separated by a dielectric filler material. The electric response can be tuned by adjusting the geometry of the top metallic electric ring resonator structure. We demonstrate that a rotation about the axis of THz wave propagation at normal incidence does not change the absorption or the resonance frequency by a significant amount. A value of absorption of 99.6 % at a resonance frequency of 0.84 THz can be achieved. We also demonstrate the characteristics of this absorber structure under various THz wave incidence angles, with respect to both the incident electric and magnetic fields.

8363-20, Session 6

Subwavelength, multimode, tunable plasmonic terahertz lenses and detectors

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We report on sub-wavelength THz plasmonic lenses based on 2 dimensional electron gas (2DEG) at AlGaN/GaN interface and also on few-layer graphene sheets. The grating gate devices in the literature had linear geometry which has polarization dependent responsivity. Circular gratings concentrate THz electric field into deep sub-wavelength area by plasmonic excitations polarization independently. Focusing of the plasmons in visible regime has been reported by several methods but in THz range plasmon focusing into deep sub-wavelength has not been observed yet.

The lenses theoretically and experimentally investigated in this study consist of concentric circular metallic gratings placed on AlGaN layer and on silicon dioxide layer that is on top of graphene. Strip width of the rings and the separation between the rings were varied. Propagation of a broadband pulse of EM waves in 0.5-10 THz was simulated by using a commercial FDTD simulation tool. The results show that concentric plasmonic grating structures can be used to concentrate THz into deep sub-wavelength areas and achieve very large field enhancements by plasmonic confinement which can be used as a detector and it can be used in sub-wavelength imaging. Optimal geometries for plasmon focusing were investigated. Plasmonic modes are excited by incident THz radiation can be concentrated into /350 localized under the central disc. Electric field intensity under the central point can be orders of magnitude higher than the outer grating area. Plasmonic lens modes supported by system can also be tuned with an applied voltage to gratings.

8363-21, Session 6

Efficiency of the detection and identification of ceramics explosive using the reflected THz signal

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We analyze the efficiency of the SDA-method for the detection and identification of ceramics explosive using THz signal reflected from the sample. THz pulse with a few cycles falls on the explosive. Because this pulse has broad spectrum we investigate dynamics of spectral lines on many frequencies. Analyzing the reflected THz signal, containing a main pulse and sub-pulse, it is possible to detect the explosive.

8363-35, Session 6

Down-conversion detection in 300 GHz radiation using glow discharge detector (GDD)

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A miniature neon indicator lamp costing about 50 cents was found to be an excellent room temperature THz radiation detector. It is also known as a Glow Discharge Detector (GDD). A down conversion method using the GDD for 300 GHz radiation is presented in this work. Previous results with the GDD at 10 GHz showed 40 times better sensitivity in down conversion detection compared to direct detection with very low power local oscillator radiation. Preliminary results at 300 GHz also showed similar improvement in down conversion compared to direct detection.

The experimental set-up is composed of two THz sources based on RF multipliers. We present an experimental setup for down-conversion using two THz sources with low power radiation. The first is a 300 GHz source and the second is 300 GHz+ f source, where f stands for the frequency difference between the two sources whose value in this experiment is about 20KHz. Using a beam splitter configuration we combine the two beams and direct them to the GDD. Since the GDD is a square law detector, the difference frequency, f, is obtained and detected in the electronics circuits. In this configuration better sensitivities were achieved as compared to direct detection. We anticipate better detection performance for higher values of f due to lower detector noise at higher frequencies, and for higher local oscillator powers.

8363-22, Session 7

Rigorous modal analysis of THz quantum cascade lasers

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The emerging THz technology is creating significant interest due to many novel applications, including spectroscopy, sensing and imaging. Amongst various sources available for THz generation, the quantum cascade lasers (QCL) are showing their maturity as compact systems.

The mode confinement of THz wave with wavelength in the mm range can only be achieved in sub-wavelength dimension by exploiting plasmonic confinements. The formation of the supermodes at the various metal-dielectric interfaces within a two-dimensional waveguide is complex in nature [1]. A rigorous full vectorial finite element base mode solver is used to study mode formation of such QCL structures. Subsequently, impacts of adverse inter modal interaction in terahertz quantum cascade laser waveguides [2] will also be presented here.

[1] H. Tanvir, B.M.A Rahman, N. Kejalakshmy, A. Agrawal, K.T.V Grattan, “Evolution of Highly Confined Surface Plasmon Modes in Terahertz Quantum Cascade Laser Waveguides,” IEEE/OSA J. Lightwave Technol., vol. 29, no. 14, pp. 2116 - 2125, 2011.

[2] H. Tanvir, B.M.A Rahman and K.T.V Grattan, “Impact of ‘Ghost’ Mode interaction in Terahertz Quantum Cascade Lasers,” IEEE Photonics J., vol. 03, no. 05, pp. 926 - 935, 2011.

8363-23, Session 7

Terahertz polarimetry based on metamaterial devices

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Polarimetry is a well-developed technique in radar based applications and stand-off spectroscopic analysis at optical frequencies. Extension to terahertz (THz) frequencies could provide a breakthrough in spectroscopic methods since the THz portion of the electromagnetic spectrum provides unique spectral signatures of chemicals and biological molecules, useful for filling gaps in detection and identification. Distinct advantages to a THz polarimeter include enhanced image-contrast based on differences in scattering of horizontally and vertically polarized radiation, and measurements of the dielectric response, and thereby absorption, of materials in reflection in real-time without the need of a reference measurement. To implement a prototype THz polarimeter, we have developed low profile, high efficiency metamaterial-based polarization control components at THz frequencies. Static metamaterial-based half and quarter waveplates operating at 0.35 THz frequencies were modeled and fabricated, and characterized using a MHz resolution, continuous-wave spectrometer operating in the 0.09 to 1.2 THz range to verify the design parameters such as operational frequency and bandwidth, insertion loss, and phase shift. The operation frequency was chosen to be in an atmospheric window (between water absorption lines) but can be designed to function at any frequency. Additional advantages of metamaterial devices include their compact size, flexibility, and fabrication ease over large areas using standard microfabrication processing. Waveplates in both the transmission and reflection mode were modeled, tested, and compared. Data analysis using Jones matrix theory showed good agreement between experimental data and simulation.

8363-24, Session 7

Ultrahigh-sensitive plasmonic terahertz detectors based on an asymmetric dual-grating gate HEMT structure

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[Invited] We report on ultrahigh sensitive, broadband terahertz (THz) detectors based on asymmetric double-grating-gate (A-DGG) high-electron-mobility transistors (HEMTs). Hydrodynamic nonlineari¬ties of two-dimensional (2D) plasmons in HEMTs are promising for fast and sensitive rectification/detection of THz radiation, which can be applied to real-time THz imaging/spectro¬scopic analysis and future THz wireless communica¬tions. Recently, InP- and GaN-based HEMTs as well as Si-MOSFETs have demonstrat¬ed improved responsivities, approaching 1 kV/W at 1 THz by introducing narrow-band dipole antenna structure merged with the gate electrode. We propose an A-DGG structure that can greatly enhance the asymmet¬ry of the cavity boundaries by applying different gate voltages to the two different sub-gratings of the A-DGG. Strong build-in asymmetry in the unit cell of the structure can be created by introducing the A-DGG structure. The THz photoresponse dramati¬cally increases if the parts of 2D channel under the fingers of one of the two sub-gratings are depleted. A-DGG HEMTs have been designed and fabricated using InAlAs/InGaAs/InP material systems. Asymmetric factor, the ratio of the inter-finger spaces, d1/d2, was fixed to be 0.5. We conducted room temperature THz photovol¬taic measurements with the fabricated detectors using a ring-cavity THz paramet¬ric oscillator source delivering tunable monochromatic THz pulsed waves with frequencies from 1 to 3 THz. A record-breaking responsivity 2.2 kV/W and an excellent noise equivalent power 15 pW/Hz0.5 were obtained at 1 THz. A fairly high responsivity (>0.5 kV/W) was maintained over the frequency beyond 2 THz. All these values are, to the authors' knowledge, the best ever reported at these frequencies.

8363-25, Session 7

Plasmonic gratings for photoconductive terahertz generation: eliminating the need for short-carrier lifetime semiconductors

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Photoconductive terahertz sources have been the most commonly used devices for generating terahertz waves. Ultrafast operation of photoconductive terahertz sources is generally achieved by using short-carrier lifetime semiconductors. The shortcoming of using short-carrier lifetime semiconductors is a significant reduction in photoconductor quantum efficiency because of the high carrier recombination rates, low carrier mobility levels, and low thermal conductivity levels of short-carrier lifetime semiconductors.

In this work we present, for the first time, a photoconductive terahertz emitter, which employs plasmonic photoconductor contact electrodes to enable high quantum efficiency and ultrafast operation simultaneously, eliminating the need for short-carrier lifetime semiconductors. Photoconductor contact electrodes consist of plasmonic gratings designed such that surface plasmon waves can be excited at the metallic grating surface. Excitation of surface plasmon waves assists with efficient transmission of the pump optical beam, through the subwavelength gratings, into the photoconductor active region. Additionally, due to excitation of surface plasmon waves, the intensity of the transmitted optical pump is enhanced in close proximity with photoconductor contact electrodes, reducing the average photo-generated carrier transport time to photoconductor contact electrodes. Therefore, high quantum efficiency and ultrafast operation are achieved simultaneously while eliminating the need to use low-mobility, short-carrier lifetime semiconductors. By integrating plasmonic photoconductors with a 0.5THz dipole antenna on a low-defect In0.53Ga0.47As substrate and measuring the photoconductor response time in a time-domain spectroscopy setup, a 670fs FWHM response time is measured. The demonstrated 670fs response time indicates the impact of plasmonic electrodes to allow ultrafast photoconductor operation without using short-carrier lifetime semiconductors.

8363-26, Session 8

A modular and adaptable system architecture for real-time terahertz imaging applications

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We report on the design, manufacture and demonstration of a new modular terahertz imaging platform. The architecture can be configured as the best solution for any particular application in terms of frame/data rate, field of view, pixel count and sensitivity. Focus has been on the 220-280GHz atmospheric water window but the platform could be reconfigured for operation anywhere between 50 to 500GHz. Up to 32 heterodyne detectors can be incorporated into a quasi 2D array. All elements of the receiver module have been integrated into a common custom package for maximum density and minimised cost, this includes the final backend RF to digital conversion.

Mechanical scanning of the input beams has been retained due to the need for efficient optical coupling and cost of the final product. However, a new electro-mechanical actuation technology has been adopted. The scanner mechanism has been specifically tailored for this application. All wearing surfaces have been removed promising infinite lifetime and near silent operation. Both axes can be driven independently with speed mainly being constrained by the power available. Position data is

provided with a sensor bandwidth of 3kHz, providing the a standard +/- 3 degree scan line update rate of 30Hz.

A comprehensive optimisation of all receiver aspects including optics, frontend mixer, backend low noise amplifier and video detector has been carried out. Preliminary tests have indicated that this has resulted in a threefold improvement in sensitivity over the previous generation. giving a ΔT of approximately 0.3K.

8363-27, Session 8

Graphene-based field-effect transistor structures for terahertz applications

A. N. Abbas, N. Pala, M. Karabiyik, C. Al-Amin, S. Das, W. Choi, Florida International Univ. (United States)

Graphene is becoming a very attractive material for optical applications. Very high mobility, long momentum relaxation time and room temperature operation are properties that make the utilization of Graphene in optoelectronic devices in the terahertz range very promising.

We report on large scale Graphene based linear Field Effect Transistor (FET) array on a few-layer Graphene for the plasmonic detection of terahertz (THz) frequencies. Large area Graphene film was synthesized using Chemical Vapor Deposition (CVD) of hydrocarbon on Copper foils at 1000°C using a flow of precursor gas mixture containing methane (CH_4) and hydrogen (H_2) and Argon (Ar). After Graphene growth, the foil was cooled down to room temperature and Graphene membrane was transferred on to a single crystal sapphire wafer by chemical etching and transfer methods. The FET array is composed of a periodic gate structure on top of Graphene which allows tunable detection under applied bias. In the structure, the periodic source and drain patterns make ohmic contacts with the Multilayer Graphene sheet while the gate is separated from Graphene by SiO_2 for plasmons propagation confinement between the metal gate and Graphene.

We have investigated the resonant absorption of Terahertz frequencies by plasmons in the proposed devices theoretically and experimentally. We observed well defined resonant modes in the 0.5-8 THz spectral range at room temperature. The resonant absorption modes are changing with the gate width and periodicity. The observed resonant frequencies are in good agreement with the analytical results for plasmonic modes in periodically patterned Graphene based structures.

8363-28, Session 8

Resonant bolometric subterahertz detection in a 2D plasmonic cavity

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A multi-gate GaAs/AlGaAs high electron mobility transistor (HEMT) coupled to a log-periodic antenna and integrated with a Si hyper-hemispherical lens was engineered to detect terahertz radiation. The channel of the HEMT functions as a 2D plasmon cavity where the source, drain and gate terminals produce bias dependent cavity boundaries. In this multi-gate design, a single gate is biased below threshold to induce a region of thermally activated transport. This functions as an integrated bolometric sensor. The additional gate or gates are then independently biased to electronically tune 2D plasmon excitations. Maxima in detector signal occur where there is optimal power absorption in the circuit formed by antenna, plasma cavity and bolometric sensor. The detector optical responsivity has been measured from 160 GHz to 450 GHz. The frequency dependent response spectrum is indicative of voltage-tunable 2D plasmon modes where the fundamental wave-vector is defined by a 2D plasma cavity. Multiple harmonics of the fundamental 2D plasmon mode are evident. In a bolometric detection mode a noise equivalent power of less than 50 pW/Hz^1/2 and a responsivity exceeding 100 kV/W have been measured at 11.5 K with 320 Hz modulation frequency. The detector time constant is a bias-dependent circuit RC time constant on the order of 1-2 ms that tracks the differential resistance of the HEMT. Both the detector responsivity and noise density are filtered by the circuit time constant above the RC cutoff frequency.

8363-29, Session 8

THz power generation from nitride-based quantum cascade laser(QCLs)

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Nitride-based terahertz quantum cascade lasers (QCLs) emit radiation due to intersubband optical transitions in semiconductor superlattsices that could be engineered by design. We demonstrate a room temperature THz generate source based upon Nitride material heterostructure, a calculated peak optical gain of 60 cm^{-1} occurs for photon energy near $h\omega$ = 3.225 eV, and the calculated current as a function of applied electric field in Nitride-based multi-quantum well is also present in this paper. Finally, a maximum THz power of 0.4448μW based on 5.547 terahertz source with continuing input current is obtained

8363-31, Poster Session

Beam-driven linear and nonlinear THz source technology

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Serious interest and progress in microwave and THz dielectric materials has arisen in part from studies of dielectric loaded wakefield accelerating structures and beam driven microwave sources. These techniques both involve dielectric cavities excited by short relativistic electron pulses. While originally developed in the context of particle accelerator technology, we investigate possible applications to compact THz sources. Besides linear dielectrics, we also discuss the properties and applications of advanced nonlinear ferroelectrics like composite BST(M) (Barium-Strontium-Titanate-MgO) in the THz regime. A ferroelectric ceramic possesses an electric-field-dependent dielectric permittivity that can be rapidly varied by an applied bias voltage pulse. Response times of ~10^-11 sec for the crystalline form and ~10^-10 sec for ceramic compounds have been measured. Ferroelectrics allow control of their dielectric properties in two directions using a single external control pulse, offering unique capabilities for high-power switching and tuning devices intended for accelerator and other rf applications. Typical values of the tunability (change in relative permittivity with a change in the electric field) are roughly 30% and can be up to 80% at 4-5 MV/m with a reasonable loss tangent of ~5×10-3 at X-band.

We will present numerical and experimental results on high frequency RF generation in dielectric devices, including tuning and efficiency studies and different options for beam excitation. Numerical electromagnetic simulations of wakefields in nonlinear dielectric structures demonstrate that wave steepening and harmonic generation occur.

8363-32, Poster Session

Comparative reconstructions of THz spectroscopic imaging for non-destructive testing and biomedical imaging

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Imaging with electromagnetic radiation in the THz frequency regime, between 0.2 THz and 10 THz, has made considerable progress in recent years due to unique properties of THz radiation, such as being non-ionizing and transparent through many materials. This makes THz imaging and sensing promising for a plethora of applications in the biomedical and pharmaceutical fields, homeland security, non-contact materials testing, etc. Terahertz Time Domain Spectroscopy (THz TDS) remains one of the most successful techniques to generate and detect THz radiation without the need for cryogenic cooling. It also enables access to both the amplitude and phase information of the traveling THz waves. As a result of the direct time-resolved detection method for the THz electric field, unique spectroscopic information about the objects traversed can be extracted from TDS measurements in addition to being able to yield intensity imaging contrast. Such spectroscopic capability is considered a unique feature of imaging based on THz TDS and can be very useful for both screening and diagnostics applications.

In this work, we present the principle and application of a unique reconstruction algorithm applied to THz spectroscopic imaging and sensing. We demonstrate its ability to achieve multi-dimensional imaging contrast in the case of both soft tissues and concealed objects, by visualizing the peak intensity, a fixed time delay in the THz waveform, or at different frequencies, as a function of the physical location in the object probed.

8363-33, Poster Session

Terahertz imaging with missing data analysis for optical metamaterials characterization

A. U. Sokolnikov, Visual Solutions and Applications (United States)

Terahertz imaging proves advantageous for optical metamaterials characterization since the interaction of THz radiation with the metamaterials produces clear patterns of the material. Characteristic “finger prints” of the crystal structure help locating defects, dislocations, contamination, etc. TDS-THz spectroscopy is one of the tools to control metamaterials design and manufacturing. A computational technique is suggested that provides a reliable way of calculation of the metamaterials structure parameters, spotting defects. Based on missing data analysis, the applied signal processing facilitates a better quality image while compensating for partially absent information. Results are provided.

8363-34, Poster Session

Development and optimization of THz NDT on aeronautics composite multilayered structures

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Modern aircraft structures have to comply with severe requirements: they have to be light and safe. These requirements lead to an increased use of composite materials in the aircraft industry. To support the high standards of composite part construction and repair, new non-destructive techniques are necessary to improve the efficacy of composite part inspection. DOTNAC (Development and Optimization of Terahertz (THz) Non-Destructive Techniques (NDT) on Aeronautics Composite multi-layered structures) proposes to develop a NDT using THz waves.

The THz spectrum covers a frequency spectrum from the far-IR (Infra Red) region to the mid-IR. Over the past several years, there has been a significant interest in the potential of THz detection for imaging: (1) Terahertz radiation is transmitted through most non-metallic and non-polarized media, (2) THz radiation poses no health risk to the system's operator.

Nowadays very little research is being performed using THz radiation for air transport NDT, and little is known on how typical composite material defects such as delamination, porosities and inclusions can be detected using THz waves. The overall approach of the DOTNAC project starts with the knowledge acquisition of the end user NDT requirements and the assessment of aeronautic relevant composite materials and occurring defects. Starting with the THz hardware research, a first process will concentrate on the development of a pulsed THz system using fibre coupling and a second one on a multi-frequency FMCW (Frequency Modulated Continuous Wave) THz system using electrical cable coupling. The pulsed THz system promises a better in-depth resolution and therefore an enhanced probability of detecting delaminations and debonds. Using the FMCW THz system a better transparency of the materials is expected because only the sub-THz frequencies are used.

These two complementary THz systems will be completed with a 3D scanner and appropriate signal and image processing. In a final step the integrated imaging systems will be used to evaluate the overall potential of a THz NDT, first on calibrated, then on so-called blind samples. By comparing these measurements with the results from Ultra Sound NDT, X-ray NDT, IR Thermographic Testing, and acoustic tapping on the same samples, the THz-NDT tool can be validated and valorised with respect to the established methods.

Conference 8364: Polarization: Measurement, Analysis, and Remote Sensing X

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8364-01, Session 1

Task-specific snapshot Mueller matrix channeled spectropolarimeter optimization

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We have developed a tool to simulate reconstruction behavior of a snapshot Mueller matrix channeled spectropolarimeter in presence of a specified type of noise. A shortcoming of the device is that with a large number of channels, each channel has to be narrow, which limits the reconstruction accuracy and provides a strong bandlimit constrain on the object. The concept of making partial Mueller matrix measurements can be extended to a channeled system by considering polarimeter designs that interfere irrelevant Mueller matrix elements, while decreasing the number of channels and subsequently increasing the available bandwidth to each channel. This tool optimizes the distribution of the available bandwidth towards the polarization elements that we care about most.

A generic linear systems model of a spectropolarimeter with four variable retarders allows us to construct a matrix that maps Mueller matrix elements into corresponding channels. A pseudo-inverse of that matrix enables the reconstruction of Mueller matrix elements from channels. By specifying a mask matrix, we can control the subjective importance of each of the reconstructed elements and weigh their error contribution accordingly. Finally, searching the design space allows us to find a design that maximizes the SNR for a specific partial Mueller matrix measurement task.

8364-02, Session 1

Modulated polarimeter operators in the presence of stochastic signals

C. F. LaCasse IV, College of Optical Sciences, The Univ. of Arizona (United States)

Imaging modulated Stokes polarimeters require processing of acquired data to produce an estimate of the Stokes parameters from the scene. The total polarimeter operator describes not only how the Stokes parameters are transformed into flux measurements by the system analyzer vector, but also includes the processing algorithm used to estimate the Stokes parameters from the flux measurements. Most descriptions of processing algorithms in literature inherently assume that the Stokes parameters are constant over the range of the reconstruction, even though it may not be a conscious choice by the designer. Recently work has been done to develop an algorithm that will properly handle scene fluctuations provided that the fluctuations are band limited to the band limit requirement determined by the analyzer vector, which will be more strict of a requirement that the detector's nominal Nyquist band limit requirement. In this discussion will shall consider the polarimeter being applied to an application where the power spectra of the scene Stokes parameters and detector noise are known. The power spectra of the estimated Stokes parameters is found using the known power spectra of the scene to find the response of the operator to signal fluctuations of different frequencies from the various Stokes parameters. This analysis leads to the ability to optimize the polarimeter operator for a given application.

8364-03, Session 1

Mueller matrix by imaging polarimeter

C. Kim, Northrop Grumman Electronic Systems (United States); B. Thai, Northrop Grumman Aerospace System (United States); D. Edwards, Air Force Research Lab. (United States)

Most of imaging polarimeters in the field measure only a few components of the Mueller matrix or their combinations such as Stokes vector, degree of linear polarization (DOLP) and degree of circular polarization (DOCP). Our imaging polarimeter was similar in that it produced two combinations of 16 Mueller components. We upgraded our polarimeter to acquire the Mueller matrix of a scene in the field (Mueller image). Scenes consisted of flat plates mounted on a large panel, a large cylinder, and natural background such as trees and grass. We established a formula to derive Mueller images from the measurements with outdoor instrument. Mueller images provided comprehensive information about the polarization effect on any targets in the scene, which were useful in distinguishing man-made objects from natural background. In addition, Mueller images enabled us to emulate some images by imaging polarimeters with limited capability. Comparison of those images with Mueller images provided an insight on the effectiveness and shortcomings of the associated imaging polarimeters.

8364-04, Session 1

Polarimetric wavelet fractal remote sensing principles for space materials

G. C. Giakos, The Univ. of Akron (United States); R. H. Picard, P. N. Crabtree, P. D. Dao, P. J. McNicholl, Air Force Research Lab. (United States)

A new remote sensing approach based on polarimetric wavelet fractal detection principles will be introduced and the Mueller matrix formalism will be defined, aimed at enhancing the detection, identification, characterization, and discrimination of unresolved space objects at different aspect angles. The design principles of a multifunctional liquid crystal monostatic polarimetric ladar will be introduced and related to operating conditions and system performance metrics. Backscattered polarimetric signal contributions from different space materials will be studied and analyzed using correlation coefficients and wavelets combined with fractals. The depolarization, diattenuation, and retardance of the materials will be estimated using Mueller matrix decomposition for different aspect angles.

The advantages of the presented system are multiple. First, the multifunctional system is well suited for situations where polarimetric BRDF and a linear response are needed over a wide dynamic range, such as under wide variation of signal levels or under different aspect angles. The polarimetric wavelet principles would enhance the capabilities of the ladar to provide not only enhanced characterization and discrimination of the object but also would provide complementary information regarding the object orientation (aspect angle) with respect to the observer. Second, the monostatic polarimetric ladar could be easily reconfigured to operate either in a single-point-detection mode enabling BRDF measurement with enhanced small-angle scattering detection capabilities or in a multiple-point-detection format enabling texture (bidirectional texture function or BTF) measurements, which include the spatial "micro-scale" variation of the BRDF.

8364-05, Session 2

Optimization of a mid-wave tunable polarimetric optical scatter instrument

J. C. Vap, Air Force Research Lab. (United States); S. Nauyoks, M. A. Marciniak, Air Force Institute of Technology (United States)

A tunable mid-wave infrared optical scatter instrument was recently developed; the mid-wave tunability spans 4.35 to 6.5µm through the use of external-cavity quantum cascade lasers. Efforts to introduce a dual rotating retarder Mueller matrix polarimetric commenced with utilizing non-achromatic retarders (quarter-wave at 3.39µm). Despite leveraging

the measurement matrix method to optimize the rotation increments of the retarders and the number of measurements to collect, insufficient retardance existed - this was manifested in high condition numbers and errors in free-space Mueller matrix extractions. To combat these problems, achromatic 120-degree retarders were introduced to reach a near-optimum configuration. System characterization was accomplished and measurements were conducted on diffuse and specular samples. Comparisons between measurements collected in three retardance regimes are examined - less than 90 degrees, 90 degrees, and 120 degrees. Condition number analysis and error analysis are reviewed to arrive at the optimal number of measurements to collect.

8364-06, Session 2

Development and evaluation of a multispectral LWIR imaging polarimeter

D. Goldstein, D. Edwards, J. C. Savage, Air Force Research Lab. (United States)

No abstract available

8364-07, Session 2

Development of a polarization hyperspectral image projector

T. K. Ewing, H. Masterson, S. V. King, N. Gonzales, D. Elshof, Boulder Nonlinear Systems (United States)

No abstract available

8364-08, Session 2

Implementation of liquid crystal-based polarimeters: trade-off between speed and performance

L. Bigué, Univ. de Haute Alsace (France)

This work considers the implementation of polarimeters with liquid crystal (LC) cells as polarizing elements. Most works generally try to implement architectures with one or two pure retarding modulators such as nematic devices. In this case, rather thick LC devices able to provide a 2-pi retardation are generally used. Unfortunately, LC device switching speed is known to evolve as the inverse square of their thickness, which leads to practical implementations limited to a few tens of Hertz in the visible region. The alternative consisting in using much faster devices made of ferroelectric liquid crystals is not that obvious since these devices often operate in bistable mode. We show that using thinner, therefore faster nematic devices is possible with a minimal penalty in terms of performance. Therefore, several solutions can be considered. For instance, using two devices, each of them with a pi retardance can replace a single 2-pi device with much benefit in terms of speed. Performance evaluation will be performed through studying condition number or equally weighted variance.

8364-09, Session 2

Characterization of a visible/near-infrared snapshot imaging spectropolarimeter based on polarization gratings

J. Kim, M. N. Miskiewicz, M. J. Escuti, North Carolina State Univ. (United States)

Here we study a novel snapshot imaging hyperspectral polarimeter for use at visible and near infrared wavelengths. The instrument obtains both spectral and polarization information of a scene by using the unique optical properties of polarization gratings, which can be configured to produce tailorable and unique diffraction patterns on a single focal plane array. Here, we show the first full-Stokes snapshot imaging spectropolarimeter using polarization gratings, operating at VIS/NIR wavelengths. Based on a computed tomography algorithm, this imaging system can estimate high-dimensional contents including spatial, hyperspectral, and polarimetric information (i.e., full stokes parameters). The paper presents an overview of how the system works, detailed specifications of the main elements including broadband polarization gratings, calibration methodology, and preliminary demonstration results for estimating the high-dimensional information of a scene. We also discuss how this approach can be used in many fields including biomedical imaging, astronomy, and remote sensing.

8364-10, Session 3

Exact first order scattering correction for vector radiative transfer in coupled atmosphere and ocean systems

P. Zhai, Y. Hu, D. B. Josset, C. R. Trepte, P. L. Lucker, B. Lin, NASA Langley Research Ctr. (United States)

We have developed a vector radiative transfer code for coupled atmosphere and ocean systems based on the successive order of scattering (SOS) method. In order to achieve accuracy and efficiency, the scattering matrices of the atmosphere and ocean media are expanded in terms of the Wigner d functions. In the case of scattering functions with large forward peak, the delta fit technique is used to truncate the scattering forward peak. These scattering treatments both significantly reduce computational burden and maintain the accuracy at the same time. However, there are still some cases in which the expansion and truncation techniques do no work well. For instance, the scattering function of water clouds exhibits supernumerary bows for the scattering angle range of 140 to 170 degrees and catastrophic changes around the backscattering direction, if the effective variance of cloud particle size distribution is small (around 0.02). Brute force expansion of these scattering functions takes hundreds or thousands of terms even after the truncation of the forward peak. In order to overcome this difficulty, we have implemented the analytical first order scattering treatment using the exact scattering matrix of the medium in the SOS code. The expansion and truncation techniques are kept for higher order scattering. The exact first order scattering correction was originally published by Nakajima and Takana (JQSRT, 1998). A new contribution of this work is to account for the exact secondary light scattering caused by the light reflected by and transmitted through the rough air-sea interface.

8364-11, Session 3

Calibration of a visible polarimeter

M. C. Gibney, ITT Corp. Geospatial Systems (United States)

The calibration of a visible polarimeter is discussed. Calibration coefficients that provide a complete linear characterization of a polarimeter are represented in this paper by the analyzer vector, where sensor response in counts is given by the dot product of the analyzer vector and the incoming Stokes vector. Using the analyzer vector to represent the effect of the sensor on the incoming Stokes vector, we can include elements of the generated Stokes vector in the fit used to estimate the analyzer vectors/calibration coefficients. This technique allows us to alleviate some of the strict requirements usually levied on the source used to generate the calibration Stokes vectors, such as source temporal stability. A discussion of how these techniques are applied to IR polarimetric sensors will also be touched on.

8364-12, Session 3

Real-time sub-pixel registration of imagery for an IR polarimeter

J. Hanks, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

In imaging polarimetry, special consideration must be given to ensure proper spatial registration between frames. This is especially true in the IR given that the degree of polarization can often be lower than 10%. Under these types of conditions, edge artifacts caused by the differencing of unregistered frames has the potential to create a significant phantom-polarization signal. Mechanical alignment of polarization optics is typically capable of providing half-pixel registration. However, to achieve 1/10th pixel registration or better, a software based registration approach is often required. The focus of this paper is to present a real-time software solution for translational sub-pixel registration in a division-of-time IR polarimeter based on a rotating polarizer. The content of this presentation is broken into two sections: 1) Measurement of the image translation as a function of polarizer position and 2) real-time global registration of the image set via a 2-D convolution kernel. Examples of registered images are provided as well as estimates of enduring misregistration artifacts.

8364-14, Session 3

Material surface's multiband polarization characteristic analysis

Y. Zhao, Northwestern Polytechnical Univ. (China)

Polarized BRDF(pBRDF) not only quantifies the magnitude of the directional scattering, but also characterize the polarization of the scattering. To fully describe the optical properties of the object's surface, pBRDF should be used. In this paper, we proposed a new object's surface pBRDF analysis method based on multi-band polarization imaging. We first design a new imaging pBRDF measurement system, by using polarized spectrophotometer and CCD camera with liquid crystal tunable filter (LCTF). In this system, it contains 33 bands at the range from 400 to 720nm. We then analyze the existence of polarization on the object surface in a 2π space and compared the bidirectional reflectance with the bidirectional polarized reflectance. After that a new pBRDF model of object's surface is developed to show the full optical characteristics of object's surface. The experiment results indicate retrieved pBRDF data not only characterize its spectral variability and the homogeneousness of material, but also describes the color, roughness, electrical conductivity, texture, edge of the material and so on.

8364-36, Session 3

Polarimetric discrimination of atmospheric particulate matter

P. Raman, K. A. Fuller, D. A. Gregory, The Univ. of Alabama in Huntsville (United States)

A polarimeter capable of measuring the complete Mueller matrix of highly scattering samples in transmission and reflection from 300 to 1100 nm has been constructed and tested. Exploratory research has been conducted which may lead to the standoff detection of bio-aerosols in the atmosphere. The polarization properties of b-subtilis (surrogate for anthrax spore) have been compared to ambient particulate matter species such as pollen, dust and soot (all sampled onto microscope slides) and differentiating features have been identified. The application of this technique for the discrimination of bio-aerosol from background clutter has been demonstrated.

8364-15, Session 4

Relation between degree of polarization and Pauli color-coded image to characterize scattering mechanisms

S. Maitra, M. G. Gartley, J. P. Kerekes, Rochester Institute of Technology (United States)

Polarimetric image classification is sensitive to object orientation and scattering properties. This paper is a preliminary step to bridge the gap between visible wavelength polarimetric imaging and polarimetric SAR (POLSAR) imaging scattering mechanisms. In visible wavelength polarimetric imaging, the degree of polarization (DOLP) is widely used to represent the polarized component of the wave, scattered from the objects in the scene. For Polarimetric SAR image representation, the Pauli color coding is used, which is based on linear combinations of fundamental scattering matrix elements. This paper presents a relation between DOLP and the Pauli decomposition components from the color coded Pauli reconstructed image based on laboratory measurements and first principle physics based image simulations. The objects in the scene are selected in such a way that it captures the three major scattering mechanisms such as the single or odd bounce, double or even bounce and volume scattering. The comparison is done between visible passive polarimetric imaging, active visible polarimetric imaging and active radio frequency POLSAR. The DOLP images are compared with the Pauli Color coded image with |HH-VV|, |HV|, |HH +VV| as the RGB channels. From the images it is seen that the regions with high DOLP values showed high values of the HH component. This means the Pauli color coded image showed comparatively higher value of HH component for higher DOLP compared to other polarimetric components implying double bounce reflection. The comparison of the scattering mechanisms will help to create a synergy between POLSAR and visible wavelength polarimetric imaging and the idea can be further extended for image fusion.

8364-16, Session 4

Image processing: digital vs. polarization-based enhancementencoding techniques

A. M. El-Saba, Univ. of South Alabama (United States)

Image processing is a field of great interest for many applications. Nowadays it is very hard to name an application where image processing is not involved. Digital techniques remains the dominant ones applied to digital image processing with significant automation approaches that are built in image display, as in most digital cameras and digital TVs, to name few. Depending on the application, digital image processing techniques produces satisfactory accurate results. However, their main constraint is the processing time, an inherited problem associated with any digital image processing technique. On the other hand optical image enhancement techniques are polarization-based ones that simultaneously produce satisfactory accurate results and overcome the processing time constraint associated with their digital counter ones.

In this paper we present a comparison between common digital and polarization-based enhancementencoding techniques with respect to their accuracy, security and processing time.

8364-17, Session 4

Methods for presentation of polarimetric data: how do we show off polarimetry?

D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

No abstract available

8364-18, Session 5

Achromatic wave plates for the near- and mid-infrared

D. Beasley, P. D. Marlowe, Gooch & Housego, Cleveland (United States)

Achromatic wave plates are useful in various mid-IR applications, such as analyzing or controlling the spectrum available from CO2 and other lasers, and for the study of IR spectra from distant stars. Their production relies upon the technical skills of those who grow the required high quality crystals and those who fabricate the optical parts to the needed precision.

Two combinations of materials are described - one useful for light in the spectral range of the visible through the near IR and another that functions well in mid-IR applications from about 2.5 µm to 11.5 µm. Some limitations imposed by inherent material properties will also be discussed.

8364-19, Session 5

Optical tests of 200mm MWIR polarizer wafers: methodology and results

P. S. Erbach, J. L. Pezzaniti, J. Reinhardt, D. B. Chenault, D. Goldstein, Polaris Sensor Technologies, Inc. (United States)

Wiregrid polarizers are commonly employed as optical components in polarization sensitive imaging systems in the infrared wavelength band. Achieving acceptable performance from wiregrid polarizers typically requires small feature sizes and small periods, large aspect ratios, and subtle control over duty cycle. In many cases, the metrics mentioned above can be realized with manufacturing techniques developed in the semiconductor industry. However, metrology techniques commonly utilized in the semiconductor industry are not necessarily conducive to measuring the effective performance across a large substrate. They typically allow testing or inspection of only very small scale representations of the subwavelength features on the wiregrid polarizers. These techniques - for example the scanning electron micrograph, or SEM - may also damage the wiregrid polarizer. In this paper we present a non-destructive optical imaging method for measuring the performance of the entire infrared wiregrid polarizer produced on a 200mm substrate. This test method allows the users to see large scale errors present during the fabrication process that may not be visible with other metrology techniques. In addition, this technique directly correlates polarizer performance to manufacturing errors.

8364-20, Session 6

Division of focal plane spectral-polarization imaging sensor

M. Kulkarni, V. Gruev, Washington Univ. in St. Louis (United States)

We have designed, fabricated and tested a spectral-polarization imaging sensor by monolithic integration of pixelated aluminum nanowires with vertically stacked photodetectors. This novel sensor, which belongs to the class of Division of Focal Plane (DoFP) polarimeters, can detect broadband spectral information and partially polarized light with high spatial and temporal resolution. The aluminum nanowires are arranged as a collection of 2-by-2 pixels, or super-pixels. Each super-pixel comprises nanowires at four different orientations, offset by 45°. Thus, the optical field is sampled with 0°, 45°, 90° and 135° linear polarization filters. The nanowires have 140nm pitch, 70nm width and 100nm height.

Each pixel of the 128-by-128 imaging array consists of three vertically stacked photodetectors. The underlying physical principle for the operation of the sensor is that silicon absorbs light at a depth proportional to the incident wavelength. Therefore, the top photodetector, placed at 0.2 microns depth, is most sensitive to blue light; the middle photodetector, placed at 0.56 microns depth, is most sensitive to green light; and the bottom photodetector, placed at 2 microns depth, is most sensitive to red light. The imaging sensor has an overall spectral responsivity in the 300nm to 1000nm range. The sensor has a pixel pitch of 67um, well capacity of 52000 electrons, read-out noise of 65 electrons and dynamic range of 58dB. The integrated spectral-polarization sensor has extinction ratios of ~5 at 450nm and ~10 at 700nm.

We describe the architecture of the imaging sensor and present optoelectronic measurements and images obtained from our sensor.

8364-21, Session 6

A correlation-based interpolation method for division of focal plane polarimeters

X. Xu, A. Nehorai, V. Gruev, Washington Univ. in St. Louis (United States)

In this paper we proposed a new interpolation algorithm for division of focal plane polarimeters based on correlation information between neighboring pixels. Division of focal plane (DoFP) polarimeters monolithically integrate pixelated polarization filters with an array of imaging elements. DoFP sensors were realized in the infrared region. Recent developments in nanotechnology have made DoFP sensors applicable in visible spectra. The advantages of DoFP sensors are twofold. First, they capture polarization information at every frame. Second, they are compact and robust to various environmental factors. The main disadvantage is the loss of spatial resolution due to the implementation of a supper-pixel sampling paradigm at the focal plane. Therefore, these sensors produce four low-resolution images, where each image is recorded with linear polarization filter offset by 45 degrees.

We developed an interpolation algorithm that addresses the loss of spatial resolution by utilizing the correlation information between the four polarization pixels in a supper-pixel configuration. The new interpolation method is based on the following premise: if the angle and degree of linear polarization can be estimated in a given spatial neighborhood, then the unknown pixel values for the 0o image can be computed from the intensity values from the 45o, 90o and 135o images. The accuracy of the correlation based interpolation method is compared with those of super-pixel, bilinear and bicubic spline interpolation methods. The results of the regeneration of real high-resolution images demonstrate that the new algorithm outperformed other interpolation methods.

8364-22, Session 7

Optical characterization of a microgrid polarimeter

K. D. Fourspring, Z. Ninkov, Rochester Institute of Technology (United States)

A division of focal plane (DoFP) micro grid polarizer (MGPA) has been optically characterized to understand the performance of such filters. The MGPA under test is a commercial device available from Moxtek. These wire grid style polarizers use aluminum lines fabricated on a glass substrate with opaque regions surrounding individual pixels. Our approach to testing the MGPA has been to reimage them onto a detector and by placing the MGPA at an intermediate focal plane. For the purposes of characterizing the MGPA a high magnification reimaging optical system was assembled. The oversampled MGPA pixels were examined by using an adjustable analyzing polarizer. The effects of pixel throughput and cross talk are examined as a function of both wavelength and illumination f/#. A calibration procedure has been determined for the use of such devices. Differences in throughput for different pixel polarization orientations must be calibrated out using flat fields. The MGPA array was also characterized using a scanning electron microscope (SEM). From these SEM measurements, the pitch, fill factor, and aluminum thickness were measured. These physical parameters are input for a model to compare to the experimental cross talk and

throughput measurements. In preparation for attaching the MGPA directly to a CCD, an alignment tolerance analysis was completed. Based on the best achieved alignment possible the amount of cross polarized light that enters adjacent pixels can be determined which limits the maximum signal to noise ratio for this class of polarimeter.

8364-23, Session 7

Adaptive scene-based correction algorithm for removal of residual fixed-pattern noise in microgrid image data

B. M. Ratliff, Space Computer Corp. (United States); D. A. LeMaster, Air Force Research Lab. (United States)

Pixel-to-pixel response nonuniformity is a common problem that affects nearly all focal plane array sensors. This results in a frame-to-frame fixed pattern noise (FPN) that causes an overall degradation in collected data. FPN is often compensated for through the use of blackbody calibration procedures; however, FPN is a particularly challenging problem because the detector responsivities drift relative to one another in time, requiring that the sensor be recalibrated periodically. The calibration process is obstructive to sensor operation and is therefore only performed at discrete intervals in time. Thus, any drift that occurs between calibrations (along with error in the calibration sources themselves) causes varying levels of residual calibration error to be present in the data at all times. Polarimetric microgrid sensors are particularly sensitive to FPN due to the spatial differencing involved in estimating the Stokes vector images. While many techniques exist in the literature to estimate FPN for conventional video sensors, few have been proposed to address the problem in microgrid imaging sensors. Here we present a novel scene-based nonuniformity correction technique for microgrid sensors that is able to reduce residual fixed pattern noise while preserving radiometry under a wide range of conditions. The algorithm requires a low number of temporal data samples to estimate the spatial nonuniformity and is computationally efficient. We demonstrate the algorithm's performance using real LWIR data from the PIRATE microgrid sensor.

8364-24, Session 7

Plasmonic micropolarizers for full Stokes vector imaging

R. E. Hollingsworth, ITN Energy Systems, Inc. (United States); J. J. Peltzer, K. A. Bachman, P. D. Flammer, T. E. Furtak, R. T. Collins, Colorado School of Mines (United States)

Polarimetric imaging using micropolarizers integrated on focal plane arrays has been limited to the linear components of the Stokes vector because of the lack of an effective circular-selective structure. We discuss a plasmonic micropolarizing transmission filter that can be tuned for linear or circular polarization as well as wavelength selectivity through simple changes in horizontal geometry. The filter consists of a patterned metal film with an aperture in a central cavity that is surrounded by gratings. The aperture and gratings are covered with a transparent dielectric layer to form a surface plasmon slab waveguide that supports only TM polarized modes. A metal cap covers the aperture and forms a metal-insulator-metal (MIM) waveguide. The gratings couple light into surface plasmons, and the cavity width is adjusted to obtain constructive interference. Structures with linear apertures and gratings provide sensitivity to linear polarization, while structures with circular apertures and spiral gratings give circular selectivity. TE modes are cut off due to the sub-wavelength dielectric thickness in the MIM waveguide while the TM modes are transmitted, providing the potential for extremely high extinction ratios. The basic structure can be tuned to operate from blue to infrared wavelengths through geometric scaling and choice of appropriate materials. Experimental results will be presented for micropolarizers fabricated on glass or directly into the Ohmic contact metallization of Si photodiodes. Linear extinction ratios over 3000 have been measured. Good absolute agreement for both the spectral and polarization response is obtained between measurements and simulations using measured geometric parameters.

8364-25, Session 8

On the suitability of polarimetric reflectance and emission models for synthetic image generation

M. G. Gartley, Rochester Institute of Technology (United States)

Software based polarimetric image generation models and hardware based infrared scene projectors commonly utilize analytical forms of polarized bi-directional reflectance distribution function and emission models. Many of these models are based in first principles physical concepts, but in practice are configured as least error fits to measured signatures. The resulting analytical model may well describe the lab measured data points, but provide erroneous results when integrated into a wide ranging radiometric simulation environment.

In this work we present a methodology for characterizing the suitability of incorporating limited range lab measured data, usually through fitting to an analytical model, into a wider range modeling environment. We have found lab measured reflectance data can be fit to analytical models with parameters straying significantly from the the first principles physical description of the surface. This effect may be due to over parameterization or an undersampled measurement space, resulting in radiometric anomolies when integrated into a larger scale, multi-surface, multi-material, modeling environment. Our methodology consists of a series of sanity tests that each scattering and emission model configuration must pass before confidence is had in the polarimetric optical property description.

8364-26, Session 8

Examining epsilon near zero structures through effective medium theory and optical thin-film analysis

J. C. Vap, Air Force Research Lab. (United States); M. A. Marciniak, Air Force Institute of Technology (United States)

Epsilon near zero (ENZ) structures are of increasing interest, with developments initially directed at metal-dielectric material combinations and recently extended to doped semiconductor-dielectric combinations - all in an effort to drive the permittivity and wave number of the structure near zero. Metal-dielectric combinations' success has been spectrally limited to narrow wavelength regions of minimum loss in the metals, while doped semiconductor-dielectric combinations are expected to reduce this spectral rigidness. Effective medium theory has generally been applied to the front-end of multi-layered designs and has been applied in our case as well. However, post analysis of multi-layered design structures have been shown to closely match optical thin film analysis. We investigate a span of multi-layered designs - from one metal-dielectric layer to four metal-dielectric layers - of a visible ENZ design structure. Theoretical predictions are compared with experimentally retrieved material properties collected from ellipsometry. The region where effective medium theory breaks down and optical thin film analysis succeeds are examined.

8364-27, Session 9

Mueller matrix representation of a dicot leaf

V. C. Vanderbilt, NASA Ames Research Ctr. (United States); C. S. T. Daughtry, U.S. Dept. of Agriculture (United States)

The optical properties of leaves have been the subject of continuing research by the remote sensing community. Better understanding of the information contained in the spectral, polarized bidirectional reflectance

and transmittance of leaves may lead to improved techniques for identifying plant species in remotely sensed imagery as well as better estimates of plant moisture and nutritional status.

Here we report an investigation of the optical polarizing properties of several leaves of one species, Cannabis sativa, represented by a 3x3 Mueller matrix measured over the wavelength region 400-2,400 nm. (Circular polarization was not measured.) Leaves were harvested from field grown plants after flowering, immediately stored in a cool dark ice chest and measured within 24 hours. Cryogenic cold stage scanning electron micrographs document the micrometer scale characteristics of the surfaces of several additional C. sativa leaves.

Our results support the hypothesis that the leaf surface alters the polarization of incident light - polarizing off nadir, unpolarized incident light, for example - while the leaf volume tends to depolarize incident polarized light. Thus, optical polarization measurements allow the light reflected by a leaf to be divided into two parts. A polarized part displays no evidence of chlorophyll absorption, because it originates at the leaf surface where epicuticular waxes - an underlying amorphous wax substrate and tiny crystalline wax particles - reflect and polarize off nadir, non-polarized incident light. The non-polarized portion of the leaf reflectance originates primarily from the leaf volume and does exhibit evidence of chlorophyll absorption. We found no evidence of hyperspectral polarization variation.

8364-29, Session 9

Material classification using active polarimetry

I. J. Vaughn, College of Optical Sciences, The Univ. of Arizona (United States) and Advanced Optical Technologies (United States); J. S. Tyo, College of Optical Sciences, The Univ. of Arizona (United States); B. G. Hoover, Advanced Optical Technologies (United States)

No abstract available

8364-30, Session 10

Polarimetric imaging for air-accident investigation

G. J. Privett, M. Ashe, Defence Science Technology Lab. (United Kingdom); M. Greaves, Cranfield Univ. (United Kingdom); D. Holland, Royal Air Force (United Kingdom); L. Davidson, Defence Science Technology Lab. (United Kingdom)

We report a trial wherein a simple 4 CCD visible-band Polarimetric Imaging (PI) camera was fielded against aircraft debris distributed across an arid terrain, a littoral region and a small number of maritime debris targets.

A debris field realistically simulating an aircrash and a debris grid of aircraft remains were observed from an air platform flying in dry and sunny conditions.

We demonstrated PI utility in support of air accident investigation by an enhanced ability to successfully locate small targets within the scene via the use of colour enhanced and decorrelated intensity PI products.

Our results indicate that handheld PI capability may represent an effective low cost, upgrade and augmentation option for existing and future imaging systems that would support air accident investigators and assist in the cueing of more sophisticated assets and/or analyst attention.

8364-31, Session 10

Polarimetric imaging and radiometry in shallow waters

A. Tonizzo, A. Gilerson, C. Carrizo, J. P. Israel, S. A. Ahmed, The City College of New York (United States)

Imaging in scattering media with the purpose of object identification has always been a challenging task. In the ocean, and especially in the coastal areas, the situation is one of the worst: absorption and scattering by suspended and dissolved particles take away most of the information and blur the image of the target to be identified. In addition to the above mentioned issues, one has also to take into account the variability of the bottom which, being close to the surface, place an important role in the resulting integrated light field.

Our goal in this study is to gain insight into the effects of the variable environments on the complex polarized underwater realm. We analyze the polarized tridimensional underwater environment. Measurements were taken in variable oceanic (i.e. different pelagic and benthic habitats) and atmospheric (i.e. different solar elevations and azimuthal angles) conditions to access the effect of the variations of the environmental parameters on the underwater Stokes elements.

The instruments deployed were an underwater hyperspectral and multi-angular polarimeter (based on Satlantic HyperOCR radiometers), whose accuracy and exactness of results have been previously validated by the means of different radiative transfer calculations, and a green band full-Stokes polarimetric video camera (Bossa Nova Tech.) enclosed in a custom made underwater housing. The results presented here were collected during the first field deployment of the imaging camera.

An in-situ cross-calibration of the camera with the polarimeter has been obtained and the results have been used to calibrate the values of the Stokes elements in the images, both for the water column itself and for the underlying bottom.

8364-32, Session 10

Polarimetric image contrast between healthy and cancerous human tissues: experimental evidence and Monte Carlo simulations

T. Novikova, A. Pierangelo, Ecole Polytechnique (France); A. Benali, P. Validire, B. Gayet, Institut Mutualiste Montsouris (France); A. Nazac, CHU Bicêtre (France); A. De Martino, Ecole Polytechnique (France)

The experimental studies of backscattering Mueller matrix images of cervical and colon human tissues reveal significant polarimetric contrast between healthy and anomalous zones. Consequently, Mueller matrix imaging is emerging as a new fast low-cost optical technique for early cancer diagnostics and improved cancer staging.

The optimization of Mueller matrix imaging technique requires the understanding of the origin of polarimetric contrast between healthy and anomalous tissues.

The simulations of polarized light propagation within biological tissue were performed by Monte Carlo technique. The tissue was modelled as a stack of layers of different thicknesses with spherical scatterers of defined size. The bottom interface was chosen to be totally depolarizing lambertian surface. We confirmed that experimentally observed polarimetric response of both healthy and anomalous tissues with larger depolarization for circular compared to linear incident polarization can be qualitatively reproduced only when small (compared to wavelength) particles representing cell organelles were incorporated into the model [1]. In this work we investigate the impact of increasing light absorption (related to the tumour vascularization) and histologically proven increase of size and number density of both cell nuclei and organelles within the budding cancerous zone. Such factors are shown to have an influence on the polarimetric response of this zone which is always less depolarizing for both linearly and circularly polarized light compared to the healthy

tissue in our experiments.

1. M.-R. Antonelli et al. “Impact of model parameters on Monte Carlo simulations of backscattering Mueller matrix images of colon tissue,” Biomed. Opt. Express 2, 1836-1851 (2011)

8364-33, Session 10

Detection of buried IEDs and landmines using a microbolometer and MCT-based LWIR polarimetric sensors

K. P. Gurton, M. A. Felton, U.S. Army Research Lab. (United States); D. B. Chenault, J. L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

Results include data recorded at the Energetic Materials Research and Testing Center (EMRTC), located in Socorro, NM from Sept. 28- Oct. 7, 2011, in which actual munitions were buried. The test consisted of a ten day period in which the site was subjected to moderate weathering as a result of monsoon winds and rain. Preliminary data show continued detectability during the entire test period. Muti-spectral imagery in the spectral bands, (i.e., 7.5-11., 7.5-8.7, 9.0-11.1, 7.5-9.3µm), were recorded simultaneously with the polarimetric signatures and final analysis will be presented at the conference in addition to the polarimetric results.

8364-34, Poster Session

Development of polarizer in capillary optical fiber

J. Wang, Y. Tseng, National Sun Yat-Sen Univ. (Taiwan)

Capillary optical fiber, just like hollow-core photonic bandgap fiber, has a hollow core which various special functionality materials can be incorporated into. Although capillary optical fiber has higher loss since the lack of good guiding mechanism surrounding its core, it is still worthy to investing it as a platform for all-fiber device because of cost and flexibility advantages.

In this paper, the potential of developing fiber polarizer in capillary optical fiber will be discussed. The emphases of study are:

(1) fiber loss analysis: The loss of various capillary optical fibers as function core diameter and filled material index in hollow core will be analyzed. Then an optimized core size and filling material will be proposed for the realization of new type of fiber polarizer in capillary optical fiber.

(2) geometrical asymmetry effect on fiber polarization: A transversely geometrical asymmetry on capillary optical fiber will be performed with our post fiber processing machine. The extent of asymmetry degree effect on fiber polarization will be studied.

(3) Liquid crystal-filled effect on fiber polarization: A hollow core of capillary optical fiber filled with highly birefringent liquid crystal (i.e. E7) will be fabricated. Its performance as an optical fiber polarizer will be characterized. Furthermore, a comparison among various fiber polarizer technologies will be discussed.

8364-35, Poster Session

Enhanced standoff detection through polarimetric signatures

J. L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

No abstract available

Conference 8365: Compressive Sensing

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8365-01, Session 1

Redirected ell-1 greedy algorithm for sparse representations recovery

A. Petukhov, The Univ. of Georgia (United States); I. Kozlov, Algosoft Tech USA (United States)

Finding sparse representations in redundant systems is important and very important part of signal/image processing and information technologies, including data compression, transmission through noisy channels, and cryptographic encoding. In particular, this is the main tool for solving compressive sensing problems.

While in most general setting the problem has non-polynomial complexity, fast algorithms are possible under some relaxed conditions when sparsity is less than for extreme settings. One of such suboptimal methods is the relatively well-studied minimization of ell^1-norm. Candes, Wakin, and Boyd suggested reweighted ell^1 algorithm providing a significant step toward the optimality.

The next big improvement was achieved with ell^1-greedy algorithm by I.Kozlov and A.Petukhov.

Unfortunately, the computational complexity of 2 last algorithms significantly exceeds linear programming complexity used for ell^1-minimization.

Our new redirected ell^1-greedy algorithm has sparse recovery ability much higher than reweighted ell^1 and practically coinciding with a pure ell^1-greedy computationally extensive version.

At the sam time, its computational complexity is nearly complexity of linear programming.

This improvement of the efficiency was reached with direct reweighted (greedy) modification of the primal-dual interior-point algorithm.

The strategy of redirection of iterative algorithms can be used not only for extraction of sparse data with no structure but also for conditional decoding data with the known model (say, images or audio signals). In this case, the redirection is an efficient tool to control the sparse recovery of data with a special structure.

8365-02, Session 1

An entropic cost-function-based sparse recovery

A. C. Gurbuz, TOBB Ekonomi ve Teknoloji Üniv. (Turkey); M. Pilanci, Univ. of California, Berkeley (United States); O. Arikan, Bilkent Univ. (Turkey)

In this paper an entropic cost function that can be used for sparse recovery is proposed. Most of the current techniques based on compressive sensing (CS) minimizes the l1 norm of a signal instead of the desired l0 norm, since l0 norm is a non-convex and non-differentiable function and its minimization turns out to be a combinatorial problem. The proposed entropy function has favorable properties such as being a locally tight lower bound for the l0 norm, possesing computable gradients in the direction to sparser subspaces and avoiding shrinkage as opposed to l1 penalty, which are desirable properties for a cost function for sparse recovery. It is shown that the entropy function is minimized on the axes, where the signal is sparse and the gradient of the function is controlled. The negative direction of the gradient has a rotational characteristic towards smaller l0 norm points. Also the gradients of the proposed cost function are always perpendicular to the axes and the bias introduced in l1 minimization of noisy signals are not observed . However, the entropic cost is not convex and creates challenges in its optimization. Here we propose a gradient descent type iterative optimization technique. Simulations result demonstrate that the proposed method has lower average reconstruction error compared to l1 norm minimization after the transition regime.

8365-03, Session 1

An examination of the effects of sub-Nyquist sampling on SNR

B. R. Pollock, N. A. Goodman, The Univ. of Arizona (United States)

Traditional compression involves sampling a signal at the Nyquist rate, then reducing the signal to its essential components via some transformation. By taking advantage of any sparsity inherent in the signal, Compressed Sensing attempts to reduce the necessary sampling rate by combining these two steps. Currently, sampling operators are based on random draws of Bernoulli or Gaussian distributed random processes. While this ensures that the conditions necessary for noise-free signal reconstruction (incoherence and RIP) are fulfilled, such operators can have poor SNR performance in their measurements. SNR degradation can lead to poor reconstruction despite using operators with good incoherence and RIP. Due to the effects of incoherence-related signal loss, SNR will degrade by M/N compared to the SNR of the fully sampled signal (where M is the dimensionality of the measurement operator and N is the dimensionality of the representation space).

We model an RF compressive receiver where the sampling operator acts on noise as well as signal. The signal is modeled as a bandlimited pulse parameterized by random complex amplitude and time of arrival. Hence, the received signal is random with known prior distribution This allows us to represent the signal via Karhunen-Loeve expansion and so investigate the SNR loss in terms of a random vector that exists in the deterministic KL basis. We are then able to show the SNR tradeoff that exists between sampling operators based on random matrices and operators matched to the N-dimensional basis.

8365-04, Session 1

Coherence of random Toeplitz-block matrices: bounds and implications

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Consider the classical measurement model in which a signal x is observed according to y = Ax + n. Here, A is an n x N sensing matrix, while n represents noise in the system. It has been successfully argued during the last decade that under the assumption of x having no more than k << N nonzero components, one can have n << N and still reliably carry out tasks such as detection, estimation, and support recovery. The focus of this paper is on sensing matrices having a block structure, with each block being a "partial" Toeplitz matrix. Such sensing matrices arise naturally in application areas such as underwater communications, wireless networks, seismic imaging, and coded-aperture imaging. Toeplitz-structured sensing matrices have received considerable attention lately. In particular, recent works of Bajwa et al. and Rauhut et al. establish through the "restricted isometry property" that (partial) Toeplitz sensing matrices are well-suited for estimation of sparse signals. These results, however, dictate that one needs the number of rows of a Toeplitz matrix to be superlinear in the signal sparsity. This is in stark contrast to the linear scaling required in the case of (sub)Gaussian or subsampled unitary matrices commonly studied in the literature. Recently, Bajwa et al. have argued the use of two fundamental measures of coherence of sensing matrices for performance guarantees in sparse signal processing. In this paper, bounds are provided for worst-case and average coherence of random Toeplitz-block matrices. These bounds are then used to show that Toeplitz-block sensing matrices can also achieve linear scaling for certain classes of support recovery problems. The reported results are further applied to the problem of multiuser detection in asynchronous, code-division random access networks.

8365-05, Session 1

On linear block codes and deterministic compressive sampling

N. Tsagkarakis, D. A. Pados, Univ. at Buffalo (United States)

We suggest and explore a parallelism between linear block code parity check matrices and binary zero/one measurement matrices for compressed sensing. The resulting family of deterministic compressive samplers renders itself to the development of effective and efficient recovery algorithms for sparse signals that are not L-one-based. Experimental results that we include herein demostrate the utility of the presented developments.

8365-06, Session 2

Sparse iterative off the grid reconstruction with physically related basis sets

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Compressive Sensing theory details how a sparsely represented signal in a known basis can be reconstructed using less number of mesurements. However the assumed known basis are typically constructed through discritizing a continuous parameter space into grids. A typical signal which is sparse in the continuous parameter space is usually not sparse in the discrete basis since the signal parameters may not coincide with the grid centers. This phenomena decreases the utilization of CS in many applications. This paper proposes two methods to solve the off-grid or basis mismatch problems. The proposed method utilizes gradients with respect to the parameters at each grid location and apply greedy or joint perturbations to basis columns. The obtained results show that robust results with smaller reconstruction and estimation errors can be obtained.

8365-08, Session 2

Improving sparse representation algorithms for watercraft detection and classification

L. B. Smith, J. Nichols, C. C. Olson, K. P. Judd, U.S. Naval Research Lab. (United States)

This paper presents improvements to published sparse representation algorithms that lead to more practical small watercraft detection, tracking, and classification in a littoral environment. The first improvement is to the K-SVD algorithm for training overcomplete dictionaries, which are used in sparse representations. We show that that the time for training the dictionary is reduced from hours to minutes by incorporating multiple codebook update stages in each training iteration. The second enhancement is derived from obtaining sparse representations of filtered images rather than sparse representations of the images themselves. We attempt to determine which filters offer the best detection and classification. The third improvement is to sparse representation single image super-resolution algorithms, which are valuable in situations where there are too few pixels on target. This paper describes a general multi-scale approach and presents super-resolution results. Finally, this paper will present how this latest research in image processing can be applied to problems of interest to the Navy; specifically it shows the effect of these new methods on detection, tracking, and classification.

8365-09, Session 2

Low-complexity FPGA implementation of compressive sensing reconstruction

J. M. Stanislaus, T. Mohsenin, Univ. of Maryland, Baltimore County (United States)

Synthetic Aperture Radar (SAR) is an advanced radar imaging technique that provides high resolution images through finer spatial resolution compared to the normal beam-scanning method. Its image is a map of spatial distribution of reflectivity function of stationary objects. Compressive sensing (CS) is a novel technology which allows sampling sparse signals under sub-Nyquist rate. Studies are made to integrate CS with SAR since most of the SAR images are sparse in wavelet or complex wavelet transform. In radar, CS helps to use low-rate ADC and decreases the hardware used for storing sampled data. While CS has several advantages, CS reconstruction algorithms are complex and software implementation of these algorithms is extremely slower and power-hungry. Matrix manipulations are made easier in GPU's but it has the drawback on memory bandwidth. In this paper, high performance architecture for the reconstruction of compressively sampled signals is proposed. The algorithm used here is Orthogonal Matching Pursuit (OMP). The major goal in OMP is to solve the least square problem and a scalable Q-R decomposition (QRD) core is implemented to perform this. This is supported by a new fixed point fast inverse square root algorithm. The optimized architecture reconstructs a 256-length signal of maximum sparsity of 8 and using 64 measurements. Implementation on Xilinx Virtex-5 FPGA runs at two clock rates (85 MHz and 69 MHz) for a total slice count of 21656 and taking 88% of total DSP cores. The total reconstruction takes 27.12 µs which is 2.4 times faster than the state of art implementation. The design is also implemented in 65 nm CMOS which runs at 165 MHz and occupies 0.69 mm².

8365-36, Session 2

Applied compressed sensing for enabling next-generation NASA science instruments

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Compressed sensing is a new data acquisition and processing paradigm that is poised to revolutionize how science instrument data is acquired by NASA science instruments for the next several decades. This technology is applicable across a wide spectrum of science instrument types, from image detector arrays and communications receivers to radar, lidar and sensor arrays. Compressed sensing will have a profound impact on how science instruments are designed for the foreseeable future because they challenge the need for separate compression systems and data processing hardware on-board. Unlike their traditional counterparts, instruments that are designed based on compressed sensing benefit from resulting reductions in on-board data storage, on-board processing hardware complexity and power consumption. This work summarizes the progress to date for developing new planetary imagers and ultra wideband sensing systems based on compressed sensing.

8365-10, Session 3

Super-resolution code aperture spectral imaging

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The Code Aperture Snapshot Spectral Imaging system (CASSI) is a remarkable architecture that senses the spectral information of a scene using the theory of compressive sensing. The random projections in CASSI, however, are localized spatially such that each measurement contains spectral information only from a small spatial region of the data cube. This characteristic limits the application of compressive sensing in CASSI. This paper presents a multi-frame extension of the CASSI architecture by adding a second high-resolution code aperture. In the compressed sensing paradigm, our goal is to translate high-

resolution hyperspectral scenes into compressed signals measured by a low-resolution detector. A super-resolution hyperspectral image cube is attained as an inverse problem from a set of low-resolution coded measurements. Notably, super-resolution is attained not only spatially but also spectrally, where the number of spectrally resolved image planes is significantly increased. The proposed system not only offers significant savings in size, weight and power, but also in cost as low resolution detectors can be used. The proposed system can be efficiently exploited in the IR region where the price of the detectors increases rapidly with the resolution. The simulations of the proposed system show improvement up to 4dB PSNR in the reconstructed spectral data cubes. Results show that the PSNR of the reconstructed data cubes closely approaches the PSNR of the reconstructed data cubes attained with high-resolution detectors, at the cost of using additional measurements.

8365-11, Session 3

Adaptive, feature-specific spectral imaging

P. A. Jansen, M. J. Dunlop, D. R. Golish, M. E. Gehm, The Univ. of Arizona (United States)

Spectral imaging is an extension to spectroscopy that provides spectral information at each spatial location in an image. The result, known as the spectral datacube, is typically highly compressible as a result of strong spatio-spectral correlations in natural scenes. As part of the DARPA Knowledge-Enhanced Compressive Measurement (KECoM) effort, we are developing an adaptive, feature-specific spectral imager (AFSSI) for compressive spectral imaging. Our initial work focuses on a system for performing spectral classification at each spatial location and adaptively incorporates knowledge from prior measurements to design feature-based compressive measurements that dramatically reduce time-to-classification, particularly in low SNR environments.

Design of the features can be calculated via several methods. Probabalistically-weighted principal component analysis (p-PCA) is an ad hoc technique that nonetheless achieves good performance with minimal computational effort. An alternative approach, based on our common KECoM mathematical framework of task-specific information (TSI), achieves the information theoretic lower bound on time-to-classification, but at the cost of increased computational complexity.

Preliminary simulations suggest our design will reduce time-to-classification by over 250x when compared to a traditional pushbroom architecture in low SNR environments and by over 90x when compared to a feature-based architecture utilizing random (as opposed to designed) features. We will report on our most recent simulations as well as progress on design and construction of our proof-of-principle experiment-a system with spatial resolution of 256x256 and 128 spectral bands in the 400-650 nm range.

8365-12, Session 3

Compressive hyperspectral sensor for LWIR gas detection

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Focal plane arrays with associated electronics and cooling constitute a substantial proportion of the cost, complexity, size, weight, and power requirements of Long-Wave IR (LWIR) imagers. Hyperspectral LWIR imagers add significant data volume burden as they collect a high-resolution spectrum at each pixel. We report here on a LWIR Hyperspectral Sensor that applies Compressive Sensing (CS) in order to achieve benefits in these areas.

The sensor applies single-pixel detection technology demonstrated by Rice University. The single-pixel approach uses a Digital Micro-mirror Device (DMD) to reflect and multiplex the light from a random assortment of pixels onto the detector. This is repeated for a number of measurements much less than the total number of scene pixels. We have extended this architecture to hyperspectral LWIR sensing by inserting a Fabry Perot spectrometer in the optical path. This compressive hyperspectral imager collects all three dimensions on a single detection element, greatly reducing the size, weight and power requirements of the system relative to traditional approaches, while also reducing data volume.

It also supports innovative adaptive approaches to sensing, as the DMD device allows control over the selection of spatial scene pixels to be multiplexed on the detector. We are applying this advantage to the detection of plume gases, by adaptively locating and concentrating target energy. A key challenge in this system is the diffraction loss produce by the DMD in the LW. We report the results of testing DMD operation in the LW, as well as system spatial and spectral performance.

8365-13, Session 3

On exploiting interbeat correlation in compressive sensing-based ECG compression

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Compressive Sensing (CS) is an emerging data acquisition scheme with the potential to reduce the number of measurements required by the Nyquist sampling theorem to acquire sparse signals. We recently used the interbeat correlation to find the common support between jointly sparse adjacent heartbeats. In this paper, we further exploit this correlation to find the magnitude of the significant coefficients in the sparse domain. The approach used for this purpose is based on sparse bayesian learning algorithms due to its superior performance compared to other reconstruction algorithms and the fact that being a probabilistic approach facilitates the incorporation of correlation information. The reconstruction includes, in the first place, the detection of the R peaks and the length normalization of ECG cycles to take advantage of the quasi-periodic structure. Since the common support reduces as the number of heartbeats increases, we propose the use of a sliding window where the support maintains approximately constant across cycles. The sparse bayesian algorithm adaptively learns and exploits the high correlation between the heartbeats in the constructed window. Experimental results show that the proposed method reduces significantly the number of measurements required to achieve good reconstruction quality, validating the potential of using correlation information in compressed sensing-based ECG compression.

8365-14, Session 3

Compressive sensing exploiting wavelet-domain dependencies for ECG compression

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Compressive sensing (CS) is an emerging signal processing paradigm that enables sub-Nyquist sampling of sparse signals. Extensive previous work has exploited the sparse representation of ECG signals in compression applications. In this paper, we propose the use of wavelet domain dependencies to further reduce the number of samples in compressive sensing-based ECG compression while decreasing the computational complexity. R wave events manifest themselves as chains of large coefficients propagating across scales to form a connected subtree of the wavelet coefficient tree. We show that the incorporation of this connectedness as additional prior information into greedy compressive sensing recovery algorithms, such as CoSaMP and Iterative Hard Thresholding, can significantly reduce the required

number of samples to achieve good quality in the reconstruction of the electrocardiogram. This approach also allows more control over the ECG signal reconstruction, in particular, the QRS complex, which is typically distorted when prior information is not included in the recovery. The compression algorithm was tested upon records selected from the MIT-BIH arrhythmia database. Simulation results show that the proposed algorithm leads to high compression ratios associated with low distortion levels relative to state-of-the-art compression algorithms.

8365-15, Session 4

Single-image super-resolution via sparse reconstruction

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In the field of defense and security it is very important to have high resolution sensors for recognition purposes. However there are still many low resolution sensors being used, for instance due to budget limitations or weight limits. One way of increasing the resolution of the images produced by such sensors is using multi-frame super resolution algorithms. This only works if multiple frames are available and decreases the temporal resolution. In this paper we use a sparse representation of an overcomplete dictionary to increase the resolution of a single low resolution image. This allows for a higher resolution gain and no loss in temporal resolution. Special attention is given to increase the resolution of infrared images, because in general they have less resolution in comparison with visible light images. We investigated the use of different sources for the library: high resolution infrared images and visible light images. Furthermore we looked at the difference in speed and quality between a randomly sampled library and a library sampled from known high resolution images.

8365-16, Session 4

Classifying chart images with sparse coding

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We present an approach for classifying chart images by learning unsupervised features with sparse coding. Three common categories of chart images are considered in this work: bar charts, pie charts and line graphs. The system can be broken down into three steps: (1) collecting image patches from training images and conducting pre-processing techniques, (2) using the sparse coding to learn the features automatically from unlabeled data and (3) constructing pooling for feature reduction and applying the SVM for image classification. Furthermore, nothing that chart images typically contain both text and graphical objects, the proposed method also extracts text from the images and utilizes them for improving classification. The text detection module follows the similar process and can be easily integrated into the system. We prove that the text detection algorithm is scalable and thus is robust to variations of texts' size, font and array orientation. Using images drawn from the web, we conduct experiments to evaluate the system performance. The encouraging results certifies the proposed method. Based on the proposed system, further processing modules for chart image understanding are feasible.

8365-17, Session 4

An enhanced sparse representation strategy for signal classification

Y. Zhou, J. Gao, K. E. Barner, Univ. of Delaware (United States)

Sparse representation based classification (SRC) has been proven to be a very promising classifier for face recognition. Thence, it is favored to extend its power to a broader range of classification tasks in pattern recognition. SRC first codes a query signal as a linear combination over a predefined dictionary, consisting of all training samples. It then identifies the label by evaluating which class results in the minimum reconstruction error. The underlying assumption for successfully recognizing a query signal is that in the dictionary, classes are distinguishable from each other, so that same-class samples are more likely to be selected. However, in many real-world classification tasks, e.g., Iris dataset, where classes are stratified along a radius, the column-wise normalization during sparse coding forces all training samples to collapse onto a unit ball, which could confuse sparse coding algorithms in choosing the true samples. In this paper, we propose a Nearest-Farthest Neighbors based SRC to effectively classify signals. The dictionary is composed of both the Nearest Neighbors and the Farthest Neighbors. While the Nearest Neighbors are used to narrow the selection of candidate samples, the Farthest Neighbors are employed to make the dictionary redundant. The query signal is then decomposed in a greedy way similar to OMP. The proposed approach is evaluated over two face datasets, i.e., Extended YaleB dataset and AR dataset, and 4 datasets from UCI machine learning repository. The encouraging results demonstrate the feasibility of the proposed method.

8365-18, Session 4

Progressive compressive imager

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In a previous publication [A. Stern, “Compressed imaging system with linear sensors”, Optics Letters, 32(21), 3077-3079 (2007)] it was introduced several approaches for Compressive Imaging (CI) based on optically Radon Projections taken in a rotational scan-wise mode with equiangular sampling intervals. This CI systems exhibit perfect tradeoff between acquisition time and system complexity; the scanning process is of order of magnitude shorter than that of conventional imaging scanners and the imager is built of “traditional” imaging components [A. Stern, Y. Rivenson, and O. Levi, “Optically Compressed Sensing by undersampling the polar Fourier plane” J. Phys.: Conf. Ser. 206 (1) 012019 (2010).].

We have designed and built a working automatic progressive sampling imaging system based on the vector sensor concept, which utilizes a unique sampling scheme of Radon projections. This sampling scheme makes it possible to progressively add information resulting in trade off between compression and the quality of reconstruction. The uniqueness of our sampling is that in any moment of the acquisition process the reconstruction can produce a reasonable version of the image. The advantage the gradual addition of the samples is seen when the sparsity rate of the object is unknown, and thus the number of needed measurements unknown in advance. We report the good quality reconstruction from compressed data ratios of more than an order of magnitude.

8365-19, Session 4

Adaptive compressive sensing for video acquisition using a single pixel camera

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In this paper we propose a method to acquire measurements for efficient video reconstruction. As we know a single pixel camera (SPC) senses the image in a compressed form but the fact that it needs to make measurements in a sequential manner before the scene changes makes it inefficient for video imaging. In this paper we will discuss a measurement scheme that exploits the sparsity in the time domain. After acquiring all measurements required for the first frame it only acquires measurements from the areas which change in subsequent frames. The change detection is performed by calculating a few measurements at cardinal positions. These locations are determined on the basis of features which underscore the motion of objects in the scene. This technique is applicable to SPC configurations using digital mirror devices (DMDs) as the multiplexing property of the DMD array enables it to address each pixel individually and compute these features. This method is capable of real time video streaming for specific video sequences where changes

are sparse over time. We also show the reconstruction results for four test video sequences commonly used for performance analysis.

8365-20, Session 4

Compressive imaging: exploiting multiple frames for enhanced video reconstruction

J. D. Tucker, R. R. Muise, Lockheed Martin Corp. (United States)

We consider a coded aperture imaging system which collects far fewer measurements than the underlying resolution of the scene we wish to exploit. Our sensing model considers an imaging system which subsamples pixels intensities with a SLM device. We present a general approach that can be applied to compressively sensed measurements gathered with respect to our sensing model, in order to improve reconstruction quality beyond a general reconstruction algorithm. The approach exploits capturing overlapping subsequent frames in a panning camera scene or capturing novel compressively sensed measurements of the static camera scene by utilizing dynamic aperture codes. We also consider the effects of projective distortions from various camera positions of subsequent frames within our approach. The result is a decrease in the effective compression rate of the system and therefore a significantly improved compressively sensed reconstruction. Results are presented for various reconstruction algorithms on natural, man-made, and mixed scenery of panning camera scenery as well as static camera scenery.

8365-21, Session 4

Decoding of purely compressed-sensed video

Y. Liu, M. Li, D. A. Pados, Univ. at Buffalo (United States)

We consider a video acquisition system where motion imagery is captured only by direct compressive sampling (CS) without any other form of intelligent encoding/processing. In this context, the burden of quality video sequence reconstruction falls solely on the decoder/player side. We describe a video CS decoding method that implicitly incorporates motion estimation via sliding-window sparsity-aware recovery from locally estimated Karhunen-Loeve bases. Experiments presented herein illustrate and support these developments.

8365-34, Poster Session

Remote sensing images recognition based on constrained independent component analysis via compressed sensing

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It is always difficult and time consuming to process remote sensing image, because of its great amount of data. In addition, a lot of noise contained in the image makes serious impact on the data processing results. With the development of information technology, Compressed Sensing (CS) theory has performed a great effect on reducing the information storage and computation. More and more signal acquisition system based on compressed sensing is developed. Based on this, establishing a new information processing mechanism achieving the better result as before can shorten the time greatly, and reduce the waste of resources effectively. Therefore, it is necessary to study on processing remote sensing image based on CS.

In this paper, according to the feature of remote sensing image, a method based on ICA via CS is put forward to realize the goal of remote sensing image recognition. Compressed sensing signal which acquires via random observation is used as the constraint conditions of ICA. By using abundance nonnegative restriction and the abundance sum-to-one constraint, an Adaptive Abundance Modeling (AAM) algorithm is proposed in order to ensure the reliability of the objective function. Then the feature space based on Constrained Independent Component Analysis (CICA) of sparse signal is established, so as to achieve recognition quickly. Experimental results show that the proposed algorithm can obtain more accurate results as high as 90%, and improve the timeliness effectively.

8365-35, Poster Session

Compressive sensing-based image denoising using adaptive multiple samplings and reconstruction error control

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Image denoising is a fundamental image processing method for improving the overall quality of images. It is more important for remote sensing images because they require significantly higher visual quality than others. Conventional denoising methods, however, tend to over-suppress high-frequency details. To overcome this problem, we present a novel compressive sensing (CS)-based noise removing algorithm using adaptive multiple samplings and reconstruction error control. We first decompose an input noisy image into flat and edge regions, and then generate 8x8 block-based measurement matrices with Gaussian probability distributions. The measurement matrix is applied to the first, the second, and the third-level wavelet transform coefficients of the input image for compressive image sampling. For reconstruction of each block, the orthogonal matching pursuit (OMP) is applied to reconstruct each block of separate region. In the reconstruction process, we use the different error threshold values according to both the decomposed region and the level of the wavelet transform. The first level wavelet coefficients in the edge region have the lowest error threshold, whereas the third level wavelet coefficients in the flat region have the highest error threshold. We can obtain the reconstructed image without noise based on the property of the probability distribution of measurement matrices and error threshold value. Experimental results demonstrate that the proposed method removes noise better than existing state-of-the-art methods in the sense of both objective (PSNR/MSSIM) and subjective (visual quality) measures. We also present how to implement the proposed denoising algorithm for remote sensing images with analysis of computational load.

8365-22, Session 5

CHOCS: a framework for estimating compressive, higher-order cyclostationary statistics

C. W. Lim, M. B. Wakin, Colorado School of Mines (United States)

The framework of computing Higher Order Cyclostationary Statistics (HOCS) from an incoming signal has proven useful in a variety of applications over the past half century, from Automatic Modulation Recognition (AMR) to Time Difference of Arrival (TDOA) Estimation. Much more recently, a theory known as Compressive ensing (CS) has emerged that enables the efficient acquisition of high-bandwidth (but sparse) signals via nonuniform low-rate sampling protocols. While most work in CS has focused on reconstructing the high-bandwidth signals from nonuniform low-rate samples, in this work we consider the task of inferring the modulation of a communications signal directly in the compressed domain, without requiring signal reconstruction. We show that the HOCS features used for AMR are compressible in the Fourier domain, and hence, that AMR of various linearly modulated signals is possible by estimating the same HOCS features from nonuniform compressive samples. We provide analytical support for the accurate approximation of HOCS features from nonuniform samples, present practical rules for classification of modulation type using these samples, and validate our proposed rules on simulated data.

8365-23, Session 5

Tracking the sparseness of the underlying support in shallow water acoustic communications

A. Sen Gupta, J. Preisig, Woods Hole Oceanographic Institution (United States)

Tracking the shallow water acoustic channel in real time poses an open challenge towards improving the data rate in high-speed underwater communications. Multipath arrivals due to reflection from the moving ocean surface and the sea bottom, along with surface wave focusing events, lead to a rapidly fluctuating complex-valued channel impulse response and associated Delay-Doppler spread function that follow heavy-tailed distributions. The sparse channel or Delay-Doppler spread function components are difficult to track in real time using popular sparse sensing techniques due to the coherent and dynamic nature of the optimization problem as well as the time-varying and potentially non-stationary sparseness of the underlying support. We build on related work using non-convex optimization to track the shallow water acoustic channel in real time at high precision and tracking speed to develop strategies to estimate the time-varying sparseness of the underlying support. Specifically, we employ non-convex manifold navigational techniques to estimate the support sparseness to balance the weighting between the L1 norm of the tracked coefficients and the L2 norm of the estimation error. We validate the efficacy of our methods against simulated as well as experimental field data collected at 200 meters range, 15 meters depth and varying wind conditions.

8365-24, Session 5

Random versus structured projections: compressed channel sensing for underwater communications with waveguide constraints

Z. Tian, Michigan Technological Univ. (United States)

Underwater acoustic channels have rich selectivity in time, frequency, space and Doppler. These channel features need to be properly modeled and captured for effective channel equalization and data communication. However, estimation of high-dimensional acoustic channels entails heavy implementation costs, in terms of the computational load, the required number of data samples and the processing time. Compressed sensing offers a new paradigm for sparse channel estimation by collecting a small number of samples via random projections. Each random projection captures and (equally) weights in all signal components in the search space, without relying on any structural knowledge of the search space. On the other hand, some physics-based waveguide knowledge can be made available for acoustic channels, which yields the range information for the angle of arrivals based on the transmitter and receiver geometry. A structure-based projection approach is hence motivated for data sampling and channel reconstruction. Balancing between structured versus random projections, this paper develops efficient algorithms for compressed sensing under partial structural knowledge. Structured projections are applied to capture the signal energy on the known signal support, complemented by random projections that capture the residual signal components due to modeling mismatch or implementation limitation. The search space for the residual components is much sparser than the overall space, which makes it more cost effective to be reconstructed from random projections.

Broadly, the proposed techniques provide a new framework that captures the benefits of both random compressive sensing and structured active sensing, which will be useful for many sensing applications.

8365-25, Session 5

Compressive sensing of frequency-hopping spread spectrum signals

F. Liu, Y. Kim, N. A. Goodman, A. Ashok, A. Bilgin, The Univ. of Arizona (United States)

This paper introduces compressive sensing strategies to intercept Frequency-Hopping Spread Spectrum (FHSS) signals. Rapid switching of the carrier among many frequency channels using a pseudorandom sequence (unknown to the eavesdropper) makes FHSS signals difficult to intercept. The conventional approach to intercept FHSS signals necessitates capturing of all frequency channels and, thus, requires the analog-to-digital converters (ADCs) to sample at very high rates in order to capture the full spectrum. Using the fact that the FHSS signals have sparse instantaneous spectra, we propose compressive sensing strategies for their interception. In our proposed system, the incoming signal is multiplied by a wideband measurement kernel and the product is sampled at a significantly reduced rate compared to the conventional approach. We develop processing algorithms that operate directly on these undersampled measurements (including compressive matched filtering and l1 minimization reconstruction followed by conventional matched filtering). We also propose several methods to optimize the measurement kernels for the task of detecting the transmitted bits, and compare these to random measurements kernels. Our measurement kernel optimization strategies are shown to increase the mutual information between the received measurements and the binary random variable representing the transmitted bits, and, thus, lead to reduced bit error rates. The proposed techniques are validated under varying signal-to-noise and compression ratios using Gaussian Frequency-Shift Keying (GFSK) modulated FHSS signals as defined by the Bluetooth specification.

8365-26, Session 6

Dictionary reduction technique for 3D stepped-frequency GPR imaging using compressive sensing and the FFT

K. R. Krueger, J. H. McClellan, W. R. Scott, Jr., Georgia Institute of Technology (United States)

Compressive sensing (CS) techniques have shown promise for subsurface imaging applications using wideband sensors such as stepped-frequency ground-penetrating radars (GPR). Excellent images can be computed using the CS techniques by exploiting the inherent sparsity in the problem. These images have much higher spatial resolution than those achieved using previous imaging techniques like beamforming. They can achieve this while also decreasing the number of measurements that must be taken during the data acquisition period. This can be a fairly significant advantage for applications like landmine detection where the time spent acquiring measurements could be extremely dangerous or expensive. However, the problem size is severely limited for 3-dimensional imaging problems which seem to require an explicit representation matrix that involves six dimensions: one frequency dimension, two spatial measurement dimensions, and three spatial target dimensions.

This paper shows how the underlying propagation model leads to a block-Toeplitz structure in two of the spatial target dimensions which can be exploited to reduce both the storage and computational complexity. This structure is caused by the translational invariance of the measurements in the horizontal target dimensions. Transforming the block-Toeplitz structure into a block-circulant structure allows the use of the FFT to give a computational time reduction of N to log(N), along with a factor of N reduction in memory for each dimension having this block-Toeplitz structure. These significant reductions in computational resources for the CS problem will increase the potential applications of imaging in any high dimensional space as long as some of the dimensions have this block-Toeplitz structure.

8365-27, Session 6

Through-the-wall moving target detection and localization using sparse regularization

M. G. Amin, F. Ahmad, Villanova Univ. (United States)

Moving target detection and localization inside enclosed structures in a fast and reliable way is one of the most important objectives in through-the-wall radar imaging and urban sensing [1]. To this end, the new framework of compressive sensing provides means for streamlining data acquisition and scene reconstruction with much fewer observations than conventional approaches. Since most of the background (exterior and interior walls, floors, furniture etc.) is stationary except for a few moving targets, the through-the-wall scene can be rendered sparse either by change detection [2] or by considering the Doppler domain [3, 4]. The difference between change detection and Doppler based approaches is that the former does not utilize sparsity in the Doppler domain. The change detection approach was considered in [5] wherein the stationary background was removed by taking the difference of the data observations over successive probing of the scene, thereby converting a populated scene to a sparse scene in range and crossrange. Sparsity-driven imaging techniques were then applied to the difference signals to detect and localize the moving targets in the range-crossrange space. In this paper, we exploit the sparsity in the Doppler domain and consider efficient joint range-crossrange-Doppler estimation of moving targets inside buildings. We establish an appropriate signal model that permits formulation of linear modeling with sensing matrices, so as to achieve reconstruction of the range-crossrange-Doppler space via sparse regularization. The performance of the sparsity-based localization scheme is evaluated using real data of humans moving behind walls, collected with a pulse-Doppler imaging radar in a semi-controlled environment at the Radar Imaging Lab, Villanova University. The results show that a sizable reduction in the data volume is achieved using the proposed approach without a degradation in system performance.

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8365-28, Session 6

Group-sparse target recovery in widely distributed MIMO radar systems

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Compressive sensing (CS) has been applied to collocated or widely separated multiple-input multiple-output (MIMO) radar systems to achieve detection performance comparable to conventional MIMO Radar approaches but with significantly fewer measurements.The performance improvement is enabled by exploring the sparsity of the targets in the target space. This paper considers the scenario of widely separated MIMO radar. It is shown that by a simple permutation of the columns of the basis matrix we can make the targets group-sparse in the target space. Exploiting group sparsity can yield significant gains in terms of target detection performance. The paper also considers clutter and investigates methods of clutter rejection prior to applying the proposed CS approach.

8365-29, Session 6

Target detection based on information theory for compressive sensing radar systems

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Target detection techniques for radar systems have been widely studied to improve target detection probability. In particular, multiple target detectors based on information theory outperform traditional correlation target detectors for radar systems. Furthermore, compressive sensing (CS) has been considered as a technique using a sparse signal acquisition with the help of an incoherent projection basis. Using CS, the required number of samples for reconstruction is much lower than that given by the Nyquist-Shannon theorem. With a transmitted signal x R**n×m, the received signal y(R**n×1) from the target can be written as y=sGx+n, where G(R**n×m) and s are the measurement matrix whose elements are drawn from N(0,1/m) and a target reflectivity, respectively, and n(R**n×1) is the additive noise. CS theories show that we can perfectly reconstruct the original signal with a very few number of samples i.e., m<<n.

Our study focuses on effectively exploiting a new concept of information theory, which is called binding information for target detection. While total correlation which is a general form of mutual information obtains the shared information among random variables with multiple counting of overlapped information, binding information extracts the common information without multiply counting. Thus, theories of total correlation and binding information to compressive radar systems enhance target detection performances and improve detection resolution. Moreover, with a suitable CS recovery algorithm (support recovery) for target detection, however, we can successfully detect targets without prior information of the number of targets (sparsity)

8365-30, Session 7

Comparison of compressive-sensing and fractional-norm algorithms in stretch pulse-doppler radar

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Stretch processing produces high-range resolution images of a radar target scene. Multiple pulses are used to both improve SNR and estimate Doppler. Due to jamming and/or electromagnetic interference, a subset of pulses can become corrupted and have to be discarded. In such cases, the data loses its periodicity and FFT-based techniques produce higher sidelobes which mask weaker scatterers. One alternative approach is compressive sensing (CS), which minimizes the norm, and another is the fractional norm (FN) technique, which uses dual space optimization and minimizes the norm, for

We perform a comparison study of CS and FN recovery algorithms to improve range-Doppler detection in stretch with missing data. We adapt the FN algorithm in [1] to handle 2-D signals. The work in [2] recast the stretch signal model into the CS framework, used the greedy ROMP algorithm for scatterer reconstruction, and showed that the coherence of the stretch dictionary is too large to allow Doppler estimation from a single pulse (due to velocity-induced chirp phase component). We remedy the coherence problem by approximating the stretch dictionary by the spectral matrix, while keeping the chirp component in the stretch signal. This simplification is also performed in the FN algorithm. Furthermore, in both ROMP and FN, all multiplications between the dictionary and residual vectors are replaced by 2-D FFT operations, to make the algorithms computationally feasible for practical problem sizes. Preliminary results show that CS and FN approaches yield similar performance, although the FN algorithm is less dependent on sparsity of the target scene and less prone to convergence failures.

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8365-31, Session 7

Band-limited random waveforms in compressive radar imaging

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Compressive sensing makes it possible to recover sparse target scenes from under-sampled measurements when uncorrelated random-noise waveforms are used as probing signals. The mathematical theory behind this assertion is based on the fact that Toeplitz and circulant random matrices generated from independent identically distributed (i.i.d) Gaussian random sequences satisfy the restricted isometry property. In real systems, waveforms have smooth, non-ideal autocorrelation functions. In this paper, we extend the existing theory to incorporate such non-idealities and analyze the resulting performance degradation.

Compressive stochastic-waveform radar imaging involves inverting the linear equation, z=As+η, where zR**n×1 is the reflected signal, AR**n×m is a Toeplitz or circulant matrix generated from the transmit signal, sR**n×1 is the target scene, and ηR**n×1, η(sub)i~N(0,σ**2) is additive noise. Recent papers have considered the case where A=(A1,A2,....,Am) Transpose with A1 as a sequence of Gaussian i.i.d random variables, and A2,.....Am as cyclic permutations of A1. In order to account for errors arising from sampling band-limited waveforms, we solve the problem where the vector generating the matrix A, i.e. A1, is a sequence of correlated random-variables.

8365-33, Session 7

Partially sparse reconstruction of behind-the-wall scenes

F. Ahmad, M. G. Amin, Villanova Univ. (United States)

Detection and localization of targets inside enclosed structures using radio frequency sensors are the primary objectives of urban sensing and through-the-wall imaging [1]. It is highly desirable to achieve these objectives in a fast and reliable manner. This goal is primarily challenged due to increasing demands on radar systems to deliver high resolution images in both range and cross-range, which requires use of wideband signals and large array apertures, respectively. Emerging compressive sensing (CS) techniques can be used to aid in fast data acquisition in radar imaging systems for urban sensing applications. The capability of CS to reconstruct a sparse signal from far fewer non-adaptive measurements provides a new perspective for data reduction in radar imaging without compromising the imaging quality [2]. Moving target detection and localization inside buildings lends itself readily to the CS paradigm either by removal of stationary background (clutter and stationary targets) via change detection or through exploiting sparsity in Doppler domain. However, these means are not available when targets of interest are stationary. In this paper, we apply the idea of partial sparsity to scene reconstruction associated with through-the-wall radar imaging of stationary targets. Partially sparse recovery considers the case when it is known a priori that the solution vector consists of two parts, one of which is sparse and the other is expected to be dense [3-4]. More specifically, we consider the scene reconstruction problem involving a few stationary targets of interest when the building layout is assumed known. This implies that the support of the dense part of the image corresponding to the exterior and interior walls is assumed known. This knowledge may be available either through building blueprints or from prior surveillance operations. Using numerical EM modeling data, we demonstrate the effectiveness of the partially sparse reconstruction of stationary through-the-wall scenes.

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8365-37, Session 7

A high resolution SWIR camera via compressed sensing

M. Herman, InView Technology Corp. (United States)

No abstract available

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8366-01, Session 1

Next generation Klarite substrates for targeting biological sensing

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There is an increasing need and challenge for early rapid and accurate detection, identification, and quantification of chemical, biological, and energetic hazards in many fields of interest (e.g., medical, environmental, industrial, and defense applications). Increasingly to meet these challenges, researchers are turning interdisciplinary approaches combining spectroscopy with nanoscale platforms to create technologies that offer viable and novel solutions for today's sensing needs. One technology that has gained increasing popularity to meet these needs is surface enhanced Raman scattering (SERS). SERS is particularly advantageous as it does not suffer from interferences from water, requires little to no sample preparation is robust and can be used in numerous environments, is relatively insensitive to the wavelength of excitation employed and produces a narrow-band spectral signature unique to the molecular vibrations of the analyte.

SERS enhancements (chemical and electromagnetic) are typically observed on metalized nanoscale roughened surfaces. For ideal SERS sensing, commercially available uniform and reproducible nanoscale surface demonstrating high sensitivity are desirable. Additionally, if these surfaces can be modified for the selective sensing of hazard materials, an ideal sensor platform for dynamic in field measurements can be imagined.

In this proceedings, preliminary efforts towards the characterization and application of commercially available next generation Klarite substrates will be demonstrated. Additionally, efforts toward chemical modification of these substrates, through peptide recognition elements can be used for the targeting sensing of hazardous materials will be explored.

8366-02, Session 1

Multispectral diode-laser-based shifted excitation Raman difference spectroscopy for biological sample identification

K. Sowoidnich, H. Kronfeldt, Technische Univ. Berlin (Germany)

Raman spectroscopy is a well established analytical method with applications in many areas, e.g. analysis of biological samples. To overcome the problem of an undesired fluorescence background masking the Raman signals we present a multi-spectral approach using shifted excitation Raman difference spectroscopy (SERDS). For our investigations we applied microsystem diode lasers which realize two slightly shifted excitation wavelengths required to perform SERDS at 488 nm, 671 nm, and 785 nm.

The emission at 488 nm with an optical power of up to 30 mW and a spectral shift of 0.3 nm (12 cm-1) is realized by frequency doubling of a 976 nm distributed feedback (DFB) diode laser. The 671 nm laser diode contains two separate laser cavities (spectral shift: 0.7 nm (13 cm-1)) each incorporating a volume Bragg grating as frequency selective element. In that case, optical powers up to 50 mW can be obtained. For investigations at 785 nm we used a DFB laser with a maximum optical power of 110 mW and a spectral shift of 0.5 nm (7 cm-1).

Meat, fat tissue, connective tissue and bones from pork and beef were used as test samples to demonstrate the effective background removal using SERDS. For all three wavelengths integration times of only 5 - 10 seconds were necessary showing the possibility of SERDS for rapid sample identification. A comparison with conventional Raman spectra is given pointing out the improvement of spectral quality. The applicability of SERDS for other analytical applications, e. g. medical diagnosis will be discussed.

8366-03, Session 1

Infrared surface plasmons polaritons on polyaniline/graphite composite

M. Shahzad, G. Medhi, R. E. Peale, Univ. of Central Florida (United States); W. R. Buchwald, Solid State Scientific Corp. (United States); Y. Liao, C. Alber, V. Johns, Univ. of Central Florida (United States)

Conducting polymers have been used widely in sensing applications. Polyaniline is one of the most promising materials for spectral sensing of bio-molecules based on surface plasmons due to its having a plasma frequency in the mid-IR, though it is difficult to prepare films with sufficiently high conductivity. We chemically prepared a composite material of polyaniline co-doped with hydrochloric and camphorsulphonic acid in aqueous solution together with colloidal graphite, which is a semi-metal. A solution of the composite material was prepared in m-cresol, an organic solvent, resulting in a material having conductivity that exceeds either intrinsic polyaniline or graphite alone. The composite solution was spinned coated on silicon or glass substrate, its thickness was measured using Atomic Force Microscopy, IR optical constants were determined using ellipsometry out to 40 micron wavelength, and FTIR spectra confirmed the expected skin depth. Experimental and theoretical investigation of infrared surface plasmons on this composite material based on resonant absorption features experimentally measured in angular reflection spectra from gratings in wavelength range of 3 to 10 microns.

The goal is to identify a material which has potential application for surface plasmons resonance sensing with high sensitivity and selectivity in IR range.

8366-04, Session 1

SERS-TLC chip

J. Chen, J. Abell, Y. Huang, Y. Zhao, The Univ. of Georgia (United States)

Due to its powerful merits as an ultra-sensitive, label-free trace chemical sensing, surface-enhanced Raman scattering (SERS) has attracted a great deal of research attention. Traditionally, SERS has been employed for analysis of relatively pure samples in a well defined medium; however, biologically-relevant samples, such as blood or sputum, contain a mixture of components, and the resulting SERS spectra can be very complicated compared to those of pure analytes. Therefore, obtaining information about individual analyte(s) from SERS spectra of a mixture is a very challenging yet very urgent task for SERS community. The conventional method to decouple the mixture signal is to use external seperation devices or methods such as magnetic particles, microfluidic devices, to separate the components from the mixture and then use SERS to perform detection. Recently, we demonstrate that the aligned silver nanorod (AgNR) array substrates engineered by the oblique angle deposition method are capable of providing extremely high SERS enhancement factors (>10^8). The substrates are large area, uniform, reproducible, and compatible with general microfabrication process. Since the substrates consist of well aligned Ag nanorod array with defined pores, the substrate cannot only be used for SERS measurement, it can also be used for nanoscale filtration and seperation. And the simplest seperation method is thin layer chromatography (TLC).

Since the AgNR substrate has a relative large surface area, we can use it for both drpsrstion and high-sensitive detection. Here we present our results on using the AgNR array substrate to separate and detect mixture samples with two (Melamine/R6G) or three (three dyes) components. The excellent TLC performance of the AgNR arrays can spatially separate different components on the chip while SERS scan with charcaterization peaks of different components can be used to identify different component at different locations. Such a combined SERS-TLC chip will be the treand for practical application of SERS in chemical and biological sensing.

8366-05, Session 2

Miniature wearable direct reading naphthalene and VOC personal exposure monitor

W. F. Hug, R. D. Reid, R. Bhartia, M. Reid, A. L. Lane, P. Oswal, K. Sijapati, Q. Nguyen, K. Sullivan, Photon Systems, Inc. (United States)

Naphthalene has been identified by the National Research Council as a serious health hazard for personnel working with jet fuels and oil-based sealants containing naphthalene. We are developing a family of miniature, self-contained, direct reading personal exposure monitor (PEM) to detect, differentiate, quantify, and log naphthalene and other volatile organic compounds (VOCs) in the breathing zone of the wearer or in the hands of an industrial hygienist with limits of detection in the low ppb range.

The VOC-PEM provides real-time detection and data logging of exposure as well as accumulated dose, with alarms addressing long term and immediate exposure limits. We will describe the sensor, which employs optical methods with a unique excitation source and rapidly refreshable vapor concentrator.

This paper addresses the rapidly increasing awareness of the health risks of inhaling jet fuel vapors by DOD personnel engaged in or around jet fueling operations. Naphthalenes are a one to three percent component of the 5 billion gallons of jet fuels used annually by DOD. Naphthalene is also a component of many other petroleum products such as asphalt and other oil-based sealants. The Department of Defense (DOD) is the single largest user of petroleum fuels in the United States (20% of all petroleum fuel used).

The VOC-PEM provides real-time detection and data logging of exposure as well as accumulated dose. We will describe the sensor, which employs endogenous fluorescence from VOCs accumulated on a unique, rapidly refreshable, patent-pending concentrator, excited by a unique deep ultraviolet excitation source.

8366-06, Session 2

Multiplexed gas spectroscopy using tunable VCSELs

M. Bora, T. Bond, J. McCarrick, A. Chang, Lawrence Livermore National Lab. (United States)

Detection and identification of gas species using tunable laser diode laser absorption spectroscopy has been performed using vertical cavity surface emitting lasers (VCSEL). Two detection methods are compared: direct absorbance and wavelength modulation spectroscopy (WMS), in which the emission wavelength of the laser is modulated by a applying a sinusoidal component on the drive current of frequency ω, and measuring the harmonics component (2ω) of the photo-detected current. The latter method shows a better sensitivity measured as signal to noise ration, and is less susceptible to interference effects such as scattering or fouling. Gas detection was initially performed at room temperature and atmospheric conditions using VCSELs of emission wavelength 763 nm for oxygen, 1392 nm and 1854nm for water and 2012 nm for carbon dioxide, scanning over a range of approximately 10 nm, sufficient to cover 5-10 gas specific absorption lines that enable identification and quantization of gas composition. The modulation parameters, amplitude and frequency, for the WMS techniques were optimized for each detected gas species, by performing two dimensional sweeps for both tuning current and amplitude and frequency respectively. We found that the highest detected signal is observed for a wavelength modulation amplitude equal to the width of the gas absorbance lines, in good agreement with theoretical calculations, and for modulation frequencies below the time response of the lasers (<50KHz). In conclusion we will discuss limit of detection studies and further implementation and packaging of VCSELs in diode arrays for continuous and simultaneous monitoring of multiple species in gaseous mixtures.

8366-07, Session 2

Laser photoacoustic sensor for air toxic measurements

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The detection and measurement of the concentration of various environmental pollutants such as Hazardous Air Pollutants (HAPs) and toxic gases is of increasing importance. US EPA's Clean Air Act lists about 187 hazardous air pollutants or airborne toxics that are considered especially harmful to health. Numerous sensor systems have been reported for measuring these toxic gases and vapors. However, most of these sensors are specific to a single gas or able to measure only a few of them. Thus a sensor capable of measuring many of the toxic gases simultaneously is desirable. Laser photoacoustic spectroscopy (LPAS) sensors have the potential for true broadband measurement when used in conjunction with one or more widely tunable laser sources.

We describe an LPAS gas analyzer equipped with a continuous wave, room temperature IR Quantum Cascade Laser (QCL) tunable over the wavelength range of 9.3 µm to 9.8 µm for continuous real-time measurements of multiple gases/chemical components. An external cavity grating tuner was used to generate several (~87) narrow line output wavelengths to conduct photoacoustic absorption measurements of gas mixtures. We have measured various HAPs such as Benzene, Formaldehyde, and Acetaldehyde in the presence of multiple atmospheric interferents such as water vapor, carbon dioxide, and ozone etc. Using the preliminary spectral pattern recognition algorithm, we have shown our ability to measure all these chemical compounds simultaneously in under 3 minutes. Sensitivity levels of part-per-billion (ppb) were achieved with several of the measured compounds with the preliminary laboratory system.

8366-08, Session 2

Vapor plumes and chemical releases measurements with ABB hyperspectral infrared imager

L. M. Moreau, F. Prel, ABB Analytical Measurement (Canada); H. Lavoie, J. Thériault, Defence Research and Development Canada, Valcartier (Canada)

MRi is an imaging version of the ABB Bomem MR series Fourier-Transform spectroradiometer. This field instrument generates spectral datacubes in the MWIR and LWIR. It is designed to acquire the spectral signatures of rapidly evolving events.

The MRi is modular and can be configured in different ways. One of its configurations is optimized for the standoff measurements of gases in differential mode. In this mode, the instrument is equipped with a dual-input telescope to perform optical background subtraction. The resulting signal is the differential between the spectral radiance entering each input port. With that method, the signal from the background is automatically removed from the signal of the target of interest. The spectral range of this configuration extends in the VLWIR (cut-off near 14 µm) to take full advantage of the LW atmospheric window.

Recent platform developments and field trial performance measurements will be presented.

8366-09, Session 3

Surface-enhanced in-situ Raman-sensor applied in the arctic area for analyses of water and sediment

A. Kolomijeca, Y. Kwon, H. Kronfeldt, Technische Univ. Berlin (Germany)

Investigations on the seafloor in the arctic area are of great scientific interest as well as of progressive economic importance. Therefore, measurements in the water column and of sediments were carried out by applying different analytical methods. Recently developed optical techniques become of increasing interest since very compact diode lasers are available with well-defined spectral properties and optical output powers greater than 100 mW. For such optical studies Raman spectroscopy is well suited since it allows detecting "fingerprint" spectra of specific molecules. To overcome the problem of low Raman scattering intensities we applied surface-enhanced Raman spectroscopy (SERS) as strong Raman signal amplifier.

In JCR 253 arctic cruise a microsystem diode laser with reflection Bragg grating emitting at 671 nm was introduced and integrated into an optode housing which was laboratory pressure tested up to 200 bar. The connection to the mobile spectrometer is realized through an optical fiber. All performed measurements were carried out on the James-Clark-Ross research vessel during a three week experiment in August 2011.

Conventional Raman spectra and SERS spectra of arctic surface water and sediment acquired from locations around 78° N and 9° E will be presented. Selected SERS substrates developed for SERS measurements in sea-water were tested for their capability to detect different substances in the water down to very small (pmol/l) concentrations. Additionally, the applicability of shifted excitation Raman difference spectroscopy (SERDS) and a combination of SERS with SERDS for analytical applications during sea-trials for in-situ analyses of sea-water and sediments will be discussed.

8366-10, Session 3

Corrosion monitoring of reinforced concrete structures by using the 14 MeV tagged neutron beams

D. Sudac, K. Nad, Institut Ruder Bo?kovic (Croatia); R. Kollar, Napredna Energija d.o.o. (Croatia); J. Obhodas, Institut Ruder Bo?kovic (Croatia); V. Valkovic, A.C.T. d.o.o. (Croatia)

The maintenance and repair of reinforced concrete structures, especially those submerged in the sea-water, requires effective inspection and monitoring techniques for assessing the state of corrosion in reinforcement material. An underwater inspection system was developed which is able to monitor the reinforcement corrosion. The system is ROV eqquiped with the seald tube neutron generator (NG) API-120 produced by Thermo Scientific, USA. By rotating the NG and by using the associated alpha particle technique it is possible to measure the concrete cover depth together with the reinforcing bar diameter. The possibility to estimate the carbon and chloride content in the concrete was investigated.

Iron plates of different tickness, covered by 6 cm thick concrete block, were succesfully detected and the concrete cover was estimated. In addition reinforced bar of one centimeter in diameter was identified and measured.

8366-11, Session 3

Investigation of optimal size of gold nanoparticles for SERS detection of PAHs in water with 671 nm excitation

X. Shi, J. Ma, R. Zheng, C. Wang, Ocean Univ. of China (China); H. Kronfeldt, Technische Univ. Berlin (Germany)

To investigate the optimal gold colloid film properties for the detection of polycyclic aromatic hydrocarbons (PAHs) in water with 671 nm excitation wavelength, gold substrates with selected sizes of gold nanoparticles were prepared by heating (3-aminopropyl)trimethoxysilane (APTMS) methanol (or ethanol) solution. The temperature of the solutions was varied to achieve a surface plasmon resonance of the gold colloid films close to the excitation wavelength. Furthermore, the effect of size of gold nanoparticles will be evaluated. The extinction spectra show that this heating APTMS solution method can successfully control the surface plasmon resonance for surface enhanced Raman spectroscopy (SERS). In order to improve the S/N ratio of Raman spectra, a 671 nm microsystem diode laser capable to perform shifted excitation Raman difference spectroscopy (SERDS) was applied as excitation light source. In that way, the signal background in the SERS spectra was dramatically reduced and the analyte Raman peaks became clearly observable. Preliminary results, which were obtained by detecting SERS spectra of pyrene in aqueous solution at a concentration of 400 nM, demonstrate that there is an optimal size range of gold nanoparticles for excitation at 671 nm. SEM images were obtained to characterize the nanostructure of the gold colloid films. The limit of detection of pyrene as well as the dependences of the normalized intensities of characteristic bands at 409 cm-1, 588 cm-1, and 1232 cm-1 from the pyrene concentration will be presented. The results will be discussed with respect to an in-situ application for the detection of PAHs in water.

8366-12, Session 3

Solar-powered, battery-operated, atmospheric-pressure, sugar-cube size microplasma on hybrid 3D chips for elemental analysis of liquid microsamples using a portable optical emission spectrometer

X. Zhang, V. Karanassios, Univ. of Waterloo (Canada)

For the last few years [1, 5], we have been developing and characterizing miniaturized, self-igniting, atmospheric-pressure, battery operated microplasmas for use with liquid microsamples.

More recently, we used a 3d-printer to develop sugar-cube sized microplasmas. Unlike their large-scale hot-plasma counter-parts that require 1-2 kW of power and 15-20 lit/min of Ar inert gas, these cold, non-equilibrium micro-plasmas require less than 10 W of power and about 250 mL/min of support gas. In this case, the support gas was either He-Hydrogen or an Ar-Hydrogen mixture.

In this presentation, development, characterization, spectroscopic fundamentals and detection limits obtained using liquid micro-samples, a portable, fiber-optic linear-CCD spectrometer will be described.

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8366-13, Session 3

Naturally grown silver nanoparticle ensembles for 488 nm in-situ SERS/SERDS-detection of PAHs in water

Y. Kwon, Technische Univ. Berlin (Germany); R. Ossig, Univ. Kassel (Germany); A. Kolomijeca, Technische Univ. Berlin (Germany); F. Hubenthal, Univ. Kassel (Germany); H. Kronfeldt, Technische Univ. Berlin (Germany)

The detection of pollutant chemicals in water, ranging from waste water up to drinking water, is of worldwide interest. Fast response chemical sensors based on Raman spectroscopy are well suited for a rapid identification and quantification of such substances. Due to the weak Raman stray-intensity surface-enhanced Raman scattering (SERS) was applied to achieve the high sensitivity necessary for trace detection. In the European Commission funded project "SENSEnet" a SERS sensor based on naturally grown Ag nanoparticle ensembles was developed and adapted for the in-situ detection of polycyclic aromatic hydrocarbons (PAHs) in water.

Silver nanoparticle ensembles with surface plasmon resonance (SPR) wavelengths around 488 nm were prepared under ultrahigh vacuum condition by Volmer-Weber growth on quartz plates. The Raman set-up contains a frequency-doubled microsystem diode-laser which generates two emission wavelengths, 487.61 nm and 487.91 nm, making the system capable for shifted excitation Raman difference spectroscopy (SERDS). The optical output power is set to 20 mW at the SERS substrate which is located inside a flow-through cell providing continuous flow conditions of the analyte solution. The spectra were recorded using a laboratory spectrograph with a back-illuminated deep depletion CCD-detector.

We present atomic force microscope images of the developed SERS substrates as well as results for the SERS activity and limits of detection of selected PAHs, e.g. pyrene, in water with respect to the SPR wavelength. SERS/SERDS measurements of water samples containing mixtures of several PAHs (e.g. pyrene, anthracene, and fluoranthene) down to detection limits of 1 x 10-9 mol/L will be discussed.

8366-14, Session 4

An energy signature scheme for steam-trap assessment and flow-rate estimation using pipe-induced vibration measurements

G. O. Allgood, M. M. Olama, T. P. Kuruganti, J. E. Lake, Oak Ridge National Lab. (United States)

The US Congress has passed legislation dictating that all government agencies establish a plan and process for improving energy efficiencies at their sites. In response to this legislation, Oak Ridge National Laboratory (ORNL) has recently conducted a pilot study to explore the deployment of a wireless sensor system for a real-time measurement-based energy efficiency optimization framework within the steam distribution system in the ORNL campus. We make assessments on the real-time status of the distribution system by observing the state measurements of acoustic sensors mounted on the steam pipes/traps/valves. In this paper, we describe a spectral-based energy signature scheme that interprets acoustic vibration sensor data to estimate steam flow rates and assess steam traps status. Experimental results show that the energy signature scheme has the potential to identify different steam trap states and it has sufficient sensitivity to estimate flow rate. Moreover, results indicate a nearly quadratic relationship over the test region between the overall energy signature factor and flow rate in the pipe. The analysis based on estimated steam flow and steam trap status helps generate alerts that enable operators and maintenance personnel to take remedial action. The goal is to achieve significant energy-saving in steam lines by monitoring and acting on leaking steam pipes/traps/valves.

8366-15, Session 4

Application of NIR hyperspectral imaging for post-consumer polyolefins recycling

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An efficient large-scale recycling approach of particulate solid wastes is always accomplished according to the quality of the materials fed to the recycling plant and/or to any possible continuous and reliable control of the different streams inside the processing plants. Processing technologies addressed to recover plastics need to be extremely powerful, since they must be relatively simple to be cost-effective, but also accurate enough to create high-purity products and able to valorize a substantial fraction of the plastic waste materials into useful products of consistent quality in order to be economical. On the other hand, the potential market for such technologies is large and the boost of environmental regulations, and the oil price increase, has made many industries interested both in "general purpose" waste sorting technologies, as well as in developing more specialized sensing devices and/or inspection logics for a better quality assessment of plastic products. In this perspective recycling strategies have to be developed taking into account some specific aspects as i) mixtures complexity: the valuable material has to be extracted from the residue, ii) overall production: the profitability of plastic can be achieved only with mass production and iii) costs: low-cost sorting processes are required. In this paper new analytical strategies, based on hyperspectral imaging in the near infrared field (1000-1700 nm), have been investigated and set up in order to define sorting and/or quality control logics that could be profitably applied, at industrial plant level, for polyolefins recycling.

8366-16, Session 4

Rapid in-situ identification technique of oil spill developed by Gabor wavelet and support vector machines analysis based on concentration-synchronous-matrix-fluorescence spectra

C. Wang, W. Li, X. Shi, Ocean Univ. of China (China); W. Ren, J. Zhang, Beijing Normal Univ. (China)

It is urgently required to develop a rapid, effective, accurate fingerprinting technique of petroleum-related samples due to the frequent occurrence of oil spill accidents. In this paper, Concentration-Synchronous-Matrix-Fluorescence (CSMF) Spectroscopy was applied to characterize the chemical fingerprint information more comprehensively, which expanded the fluorescence information from lower ring to higher ring PAHs at different levels of concentration. For the purpose of deal with the more complicated spectra, Two-dimensional Gabor wavelet, which exhibit strong characteristics of spatial locality and high selectivity of scale and orientation, was used to extract information from CSFMs of the two data sets, one is from samples of different type oil spill, and the other is from closely-related oil source samples with the consideration of weathering and water adulteration.

An ideal result of 100% of the correct rate of oil species recognition for the different type oil spill sample set and 92% of the correct rate for the closely-related oil source samples is achieved by combining Gabor wavelet with Supported Vector Machine (SVM). The obtained results suggest that the newly-developed method may become specifically

applicable in spilled oils identification and also can be applied to other multi-fluorophoric systems such as in petroleum exploration, dissolved organic matter in environment monitoring.

8366-17, Session 4

Selective detection of heavy metal ion by calixarene-based fluorescent molecular sensor

I. Leray, Ecole Normale Supérieure de Cachan (France)

The selective and sensitive detection of cations is of great interest in various fields including biology, medecine and environment. Among the numerous analytical methods that are available for the detection of cations, (mass spectrometry, atomic absorption spectrometry) are expensive, often require samples of large size and do not allow continuous monitoring. In contrast, the methods based on fluorescent sensors offer distinct advantages in terms of sensitivity, selectivity, response time, local observation. Therefore, considerable efforts are being made to develop selective fluorescent sensors for cation detection. Such fluorescent sensors consist of a cation recognition unit (ionophore) linked to a signalling moiety fluorophore; thus they are often called fluoroionophores [1, 2, 3]. The recognition moiety is responsible for the selectivity and the efficiency of binding; therefore considerable efforts have been made to develop selective sensors for particular cations. The calixarene are good candidates because of their high selectivity and high complexation constant. The signalling moiety acts as a signal transducer, i.e. it converts the information into an optical signal expressed as the changes in the photophysical characteristics of the fluorophore. These changes are due to the perturbation (by the bound cation) of photoinduced processes such as electron transfer, charge transfer, energy transfer, excimer formation, etc.

After a general presentation of fluorescent molecular sensors for cation, particular attention will be given to the systems in which the cation perturbs the photoinduced charge transfer. In view to practical applications in medicine or in the environment, the realization of selective and sensitive system is of great interest [4-6]. In this context, several systems are presented .

8366-18, Session 5

Fundamental studies of surface-enhanced Raman scattering (SERS) using aerosolized substrates

D. A. Stuart, O. Okponyia, K. Patton, B. M. Williams, Univ. of West Georgia (United States)

We demonstrate proof-of-concept for the application of surface-enhanced Raman scattering (SERS) in remote detection and analysis. Remote Raman sensing offers great potential to address this problem of identifying a low concentration vapor phase analyte or contaminated surface. However, Raman scattering is an inherently weak process. In SERS, Raman scattering is enhanced up to 14 orders of magnitude. SERS experiments are traditionally performed either in aqueous phase or in vacuo. While SERS can be used to detect vapor phase analytes, e.g. chemical warfare agent stimulants, SERS inherently requires a surface, and a complex sampling system to get the vapor to the surface. Truly remote sensing would require us to get the surface to the analyte, and spectroscopically interrogate the system via a Raman telescope. Dispersal of an aerosolized solution of SERS active colloids, e.g. by up-wind spraying, seems the most likely method of bringing the enhancing surface to a remote location.

A disposable medical nebulizer aerosolized both the target analyte and a SERS active colloid. Although these nebulizers lack precision and control over droplet size and concentration, they approximate “real world” conditions, in which little control over dispersal conditions exist (e.g. tear gas canister, smoke stack). These “chemical clouds” were mixed in a student-designed chamber constructed from readily available inert plastic materials (viz. 2 liter soda bottle). A glass window was installed in to prevent spectral interference from the plastic chamber. Future research will focus on kinetic monitoring and improving sensitivity and selectivity by use of monolayer functionalization of the nanoparticles.

8366-19, Session 5

CELiS (compact eyesafe lidar system): a portable 1.5 µm elastic lidar system for rapid aerosol concentration measurement

M. D. Wojcik, Energy Dynamics Lab. (United States); A. Bird, Utah State Univ. (United States)

CELiS (Compact Eyesafe Lidar System) is a tactical elastic lidar system commissioned by the Strategic Environmental Research and Development Program for the purpose of air quality environmental compliance issues surrounding the offroad use of wheeled and tracked vehicles. A complete CELiS instrument weighs less than 300 lbs., is less than 2 cubic meters in volume and uses 700 W of 120V AC power. CELiS has a working range of 3 km and a range resolution of 10 m.

8366-20, Session 5

Standoff stimulated emission in air

A. Dogariu, J. Michael, R. B. Miles, Princeton Univ. (United States)

Most optical standoff identification methods rely on detecting light emitted or scattered incoherently from a remote target. A coherent light source emitting back towards the detector would significantly improve the detection distance. We are characterizing our recently demonstrated remotely induced air laser and measure the stimulated emission in atomic oxygen. The atomic oxygen is created by a remote UV laser which dissociates the oxygen molecules. The same laser excites via a two-photon transition at 226 nm the oxygen atoms, giving rise to the atomic oxygen emission at 845nm. We use a Radar Resonantly Enhanced Multi-Photon Ionization (REMPI) technique using microwave scattering to study the atomic oxygen excitation. We quantify the high gain obtained in the focusing region, and show that the strongly directional forward and backward emission shows spatial and temporal behavior characteristics to stimulated emission. We investigate the capability of our remote laser source for species detection by studying the sensitivity of the emitted beam to the changes in the optical parameters of the UV pump in the target region.

8366-21, Session 5

Use of passive and active ground and satellite remote sensing to monitor fine particulate pollutants on regional scales

L. Cordero, Y. Wu, B. M. Gross, F. Moshary, S. A. Ahmed, The City College of New York (United States)

Aerosols are solid or liquid particles suspended in the atmosphere, emitted either naturally or as the result of human activities. Aerosols study is an important topic in the environmental research because the effect of these particles in human life ranges from climate modification to health conditions. Fine particles (PM2.5) correspond to more dangerous health conditions since their sizes (2.5 µm in diameter or less) are small enough to be absorbed by the human body and to cause health complications. Health studies have shown a significant association between exposure to fine particles and premature death from heart or lung diseases. However, direct measurement of PM2.5 is very expensive, requiring sophisticated and costly particle samplers. Therefore, methods to estimate PM2.5 from remote sensing instruments both on the ground and from space are very important for air quality monitoring. In addition,

models that accurately predict particulate matter (PM) concentration are currently using more than columnar properties of aerosols since the behavior of PM has been proved to be more complex to be explained by only one variable. In this presentation, we explore the performance of current satellite (MODIS / GOES) and ground based remote sensing methods for estimation of PM2.5 and illustrate that best performance occurs during summer when AOD measurements are more accurate and the solar zenith angle is less severe. In addition, we discuss the importance of the Planetary Boundary Layer and explore the potential of meteorological forecast models and satellite measurements such as Calipso in quantifying the PBL height structure.

8366-22, Session 6

Compact laser photoacoustic spectroscopy sensor for atmospheric components measurements

W. Shi, Science & Engineering Services, Inc. (United States); G. Li, MassTech Inc. (United States); C. R. Prasad, Science & Engineering Services, Inc (United States)

It is well known that water vapor plays a crucial role in effecting the earth's weather and climate. Due to the lack of reliable long-term observations, measurements of its variability and distribution in the upper troposphere and stratosphere are sparse. NOAA's Water Vapor Sensor System is intended to fill this need, and plans to extend its sensitivity from its current threshold of 100 ppmv to 2.8 ppmv of to support operational and climate applications. Laser photoacoustic spectroscopy (LPAS) technique has the potential to provide this capability with a compact low cost instrument.

In a preliminary experiment we have built a compact LPAS sensor consisting of an inexpensive telecommunication style, fiber-coupled near IR distributed feedback laser and a short (10 cm) single-pass photoacoustic (PA) cell to demonstrate ppm level measurements of multiple atmospheric constituents. Electrical modulation of laser current is used instead of the commonly used mechanical chopper. The PA signal is enhanced by modulation at the PA cell resonant frequency and wavelength modulation spectroscopy is used to minimize the interfering background signal from the cell window absorption. Detection sensitivities of ~ 5 ppm for water vapor at 1.39 µm (5 mW), 6 ppm for CO2 at 1.6 µm (15 mW), and 3 ppm for methane at 1.6 µm (15 mW), were obtained with an un-optimized system. By increasing the laser power and optimizing the sensor we will obtain sub-ppm level measurement of water vapor. A compact LPAS sensor package designed for airborne, real-time measurements of atmospheric components will be described.

8366-23, Session 6

Chip-to-chip SnO_2 nanowire network sensors for room temperature H2 detection

A. Köck, Austrian Institute of Technology (Austria)

The employment of nanowires is a very powerful strategy to improve gas sensor performance. Due to their high surface to volume ratio they show a strong interaction with the surrounding gas. We demonstrate a novel gas sensor device, which is based on silicon chip-to-chip synthesis of ultralong tin oxide (SnO2) nanowires. The sensor device employs an interconnected SnO2 nanowire network configuration, which exhibits a huge surface-to-volume ratio and provides full access of the target gas to the nanowires. The chip-to-chip SnO2 nanowire device is able to detect humidity and H2 at room temperature. The sensor shows a linear response to humidity in synthetic air. The nanowire sensor is able to detect a H2 concentration of only 20 ppm in synthetic air with 60% relative humidity. At an operating temperature of 300°C a concentration of 50 ppm H2 results in a sensitivity of 5%. At this elevated temperature the sensor shows a linear response in a concentration range between 10 ppm and 100 ppm H2. The SnO2-nanowire fabrication procedure based on spray pyrolysis and subsequent annealing is performed at atmospheric pressure, requires no vacuum and allows upscale of the substrate to a wafer size. 3D-integration with CMOS chips is proposed as viable way for practical realization of smart nanowire based gas sensor devices for the consumer market.

8366-24, Session 6

Recent progress toward miniaturization of vacuum pumps for use in portable mass spectrometers

K. Badali, V. Karanassios, Univ. of Waterloo (Canada)

Development and characterization of miniaturized, portable analytical instruments is receiving significant attention. Such instruments can rely either on optical spectrometry or on mass spectrometry. By design, mass spectrometers require vacuum. But vacuum systems still remain relatively large, relatively heavy and are relatively power hungry. Size, weight and power requirements (due to the requirement for continuous pump operation) limit mass spectrometer portability for possible use on-site (i.e., in the field). Thus, vacuum pump a challenging hurtle to overcome, if miniaturized mass spectrometers are to successfully transition from lab-use to use in the field.

The challenges in developing and fabricating miniature vacuum pumps include: pump operating principle, pump geometry, need for precision machining, and mechanical and electronic design for high pumping-speed operation. Furthermore, most mass spectrometers developed for terrestrial uses require vacuum in the 10-5 Torr range. These challenges are amplified because a pump that provides a vacuum in the 10-5 Torr range, must also be backed-up by a roughing pump must also. So, there is a double challenge.

In this presentation, recent progress toward miniaturization of vacuum pumps will be reviewed, the challenges that must be met when developing vacuum systems for use in mass spectrometers will be outlined and attempts at developing a MEMS roughing pump without moving parts will be described in some detail.

8366-25, Session 6

Plasmonic nanoprobe systems for SERS chemical and biologicalsensing

H. Wang, T. Vo-Dinh, Duke Univ. (United States)

No abstract available

8366-26, Session 7

On-chip imaging of dense samples using pixel super-resolution-based multi-height lensfree microscopy

A. Greenbaum, U. Y. Sikora, A. Ozcan, Univ. of California, Los Angeles (United States)

Lensfree in-line holographic microscopy is an alluring alternative to conventional bright field microscopy. Combined with pixel super-resolution and iterative phase recovery techniques, it offers sub-micron resolution over a large field-of-view (~24 mm^2) together with a cost-effective, compact and light-weight design that is especially suitable for field use. Although highly advantageous for remote microscopy applications/needs, in-line holographic imaging is limited to relatively low-density samples where the reference wave is mildly perturbed by the specimen. Moreover, in order to eliminate the twin image noise, the object support needs to be automatically evaluated, which might provide a practical challenge for optically dense samples.

Here we demonstrate an alternative imaging approach to mitigate this challenge, permitting the reconstruction of contiguously connected dense

samples, without the need to evaluate their object support. This improved method is based on a phase recovery approach, which iterates back and forth among e.g., 2-5 lensfree intensity measurements (corresponding to the same specimen), each having a slightly different sample-to-sensor distance. By carefully aligning and registering these lensfree intensity measurements (acquired at different heights) to each other, we can reconstruct both phase and amplitude images of dense specimen over a large field-of-view with sub-micron resolution. We demonstrate the success of this multi-height lensfree microscopy approach by imaging dense Papanicolaou smear (i.e., Pap smear) and blood smear samples. This new approach would especially be valuable for expanding the application areas of field-portable lensfree super-resolution microscopy in e.g., resource poor settings.

8366-27, Session 7

Detection of volatile organic compounds by surface enhanced Raman scattering

A. Chang, A. Maiti, N. Ileri, M. Bora, E. Behymer, H. T. Nguyen, C. Larson, J. A. Britten, T. C. Bond, Lawrence Livermore National Lab. (United States)

There is need for compact, field-deployable, sensitive, and molecule-specific detection techniques for volatile organic compounds (VOCs) such as toluene due to their prevalence as ozone-producing air-pollutants as well as importance in certain national security applications. The VOCs have found widespread use in industry, particularly as solvents; and yet they possess significant health risks to humans and there is thus strong interest in their rapid detection in the vapor phase. Surface-enhanced Raman scattering (SERS) is attractive for this purpose because of its high sensitivity, molecule-specific fingerprinting and compatibility with real-time, in-situ remote sensing.

By exposing Ag-coated tapered nanopillars SERS substrate to toluene in the vapor phase, strong SERS signals are directly observed at various substrate temperatures ranging from -10 C to 40 C. Results from kinetics studies of the SERS signal show that the toluene adsorption saturates to a certain coverage level at temperatures above its dew point and the SERS data conform to Langmuir model of monolayer adsorption. At temperature below the dew point, the SERS kinetics exhibit more complicated behavior, and is consistent with a multilayer adsorption process as the toluene vapor condenses onto the substrate. Furthermore, our data shows that the SERS signal is strongly dependent on the concentration of the toluene vapor. We have developed a theoretical model aimed at utilizing the experimental data to provide quantitative insights such as the sticking coefficient, binding energy, adsorption barriers, and the dependence of vapor condensation on surface coverage and temperature. Such a model can then be used to deduce the fundamental detection limits of our sensor device. The methodology and model are general, and can be extended to other analytes of interest such as inorganic gases and explosives.

8366-28, Session 7

Shot-noise-limited imaging via N-photon photo-detection

W. He, Nanjing Univ. of Science & Technology (China); Y. Chen, Science and Technology on LLL Night Vision Lab. (China); Q. Chen, G. Gu, Nanjing Univ. of Science & Technology (China); W. Cheng, Science and Technology on LLL Night Vision Lab. (China)

We present the use and characterization of a Single Photon Avalanche Detector (SPAD) for shot-noise-limited imaging at ultra-low light-level. Many demanding photonic applications, such as fluorescence laser scanning microscopy, require the acquisition of very weak optical signals, generally composed by few photons mostly in the visible and near infrared wavelength. Conventional photo detector that utilizes analog current integration is generally not able to detect such low intensity signal due to the excessive noise at low signal levels. In this paper, we demonstrate shot-noise-limited imaging by scanning and using N-photon photo-detection implemented with a Single Photon Avalanche Detector. We choose a LabView based approach, extending the methods of N-photon photo-detection. In our approach, the number of TTL pulses received from the Single Photon Avalanche Detector within the duration of the pixel dwell time is recorded by a LabView pre-programmed instrument and then wrote into a pre-allocated image array, using the pixel clock and line sync signals to determine the position within the image. Experiments show that our N-photon photo-detection exhibits extreme sensitivity even down to single photon level. This characteristic of the ultra-sensitivity makes this scheme very suitable for low signal levels in fluorescence laser scanning microscopy. Related with the dynamic range, the maximum count rate of our N-photon photo-detection scheme reaches 106 counts per second (cps) while maintaining high detection efficiency. It has also been demonstrated that the thermoelectrically cooled Single Photon Avalanche Detector neutralizes dark counting noise of detector and thus obtains a nearly shot-noise-limited imaging performance.

8366-29, Session 7

Quantitative measurement of AMS and orange mixtures by terahertz time-domain spectroscopy

Q. Wang, Y. Ma, China Jiliang Univ. (China)

Mixture samples of orange and ammonium sulfamate (AMS) are measured using terahertz time domain spectroscopy

(THz-TDS), to obtain their THz time domain signals. After the Fast Fourier transform (FFT), refractive index and absorption

coefficient are calculated, to qualitatively analyze the absorption coefficient spectra of AMS in 0.2 THz-1.6THz. Meanwhile, we measured six mixture samples of AMS and orange, and then analyzed the relationship between their average absorption and concentrate by simple linear fit method. The results demonstrate that it is promising and efficient to quantitatively detect the component of mixtures by THz-TDS.

8366-30, Session 7

Early detection of combustible gas leaks using open-path infrared (IR) gas detectors

E. Naranjo, S. Baliga, General Monitors Inc. (United States)

Open-path IR gas detectors are a mainstay in the oil and gas industry. They are used in a variety of instances to identify gas accumulations or monitor gas cloud migrations. In offshore installations, open-path optical gas detectors are used to monitor drilling and production operations, crude oil separation, compression, and exhaust and ventilation systems. Because they can monitor a perimeter or fence line, they are ideally suited for detecting gas in open facilities, where point gas detectors would be difficult or expensive to deploy.

Despite their widespread use, open-path optical gas detectors are rarely employed to detect low level concentrations of combustible gases. Standard models are typically set to alarm at 50% LEL-m (50% LEL extended over one meter), providing sufficiently early warning when gas accumulations occur. Nevertheless, in cases in which a combustible gas is diluted quickly, such as ventilation exhaust ducting, it may be necessary to set the detector to alarm at the lowest predictable level. Further, interest in low level infrared gas detection has been growing as gases such as CH_4 and CO_2 are greenhouse gases.

The present paper describes a mid-wave infrared (MWIR) open-path system designed to detect combustible and carbon dioxide gas leaks in the parts-per-million-meter (ppm-m or mg/cm2). The detector has been installed in offshore platforms and large onshore facilities to detect a variety of flammable gases and vapors. Advantages and limitations of the system are presented. False alarm immunity and resilience to atmospheric interferences are also discussed.

8367-01, Session 1

Approaches for wireless physiological monitoring of dismounted soldiers

S. J. Kilpatrick, K. S. Oie, A. E. Wickenden, U.S. Army Research Lab. (United States)

Future concepts for Soldier equipment depend upon wearable sensing, computing, and power systems. Among other goals, these systems are envisioned to provide continuous monitoring and assessment of Soldier state, and to enable implementation of neurocognitive and physiologically-based technologies to enhance Warfighter effectiveness, survivability, and sustainability, and to augment situational awareness. However, current state-of-the-art capabilities for such wearable systems are largely driven by the needs of clinical and/or research end-users and remain limited, if not completely unsuitable, for implementation on the battlefield. Therefore, a significant gap exists which requires the development of technologies for wearable systems that are driven by the unique capability needs of the future Soldier-System. Future wireless body sensor networks (BSNs) for the soldier will likely need to be ultralow-power or self-powered; high-performance; autonomous; reliable; frequency adaptable; highly flexible, conformable, and stretchable where necessary; rugged; unobtrusive and noninvasive; and private and secure with efficient and robust protocols and no unwanted interferences. The U.S. Army Research Laboratory (ARL), the Army's corporate R&D center, has unique capabilities that are being brought to bear to fill this gap through the development and application of novel materials, sensors, electronics, signal and information processing, and power and energy solutions.

ARL's goals are to develop (1) truly wearable, unobtrusive, and wireless sensors that translate and extend clinical/laboratory measures of central and peripheral physiological processes to fieldable solutions; (2) low-power and/or self-sustaining integrated sensor and computing suites for fieldable implementation; and (3) efficient computational algorithms for online signal processing for accurate and reliable metrics of psychophysiological state based on wearable sensor arrays.

8367-02, Session 1

Characterization of the pigment Xanthomonadin in the bacterial genus Xanthomonas using micro- and resonance-Raman spectroscopy

M. L. Paret, Univ. of Florida (United States); A. K. Misra, T. E. Acosta, A. M. Alvarez, S. K. Sharma, Univ. of Hawai'i (United States)

Recent finding of xanthomonadin pigment in infected human bone tissue has attracted attention for its use as a potential clinical biomarker for diabetic osteomyelitis. We have used micro Raman spectroscopy with 785 nm and 514.5 nm laser excitations for characterizing the plant pathogenic bacteria Xanthomonas axonopodis pv. dieffenbachiae. This study for the first time has identified the unique Raman spectra of a carotenoid-like pigment xanthomonadin in numerous strains of Xanthomonas spp. isolated from various plant species. Xanthomonadin is a brominated aryl-polyene pigment molecule similar to carotenoids. Further studies were conducted using resonance Raman spectroscopy with 514.5 nm laser excitation on numerous strains of the bacterial genus Xanthomonas. This study revealed that the Raman bands representing the vibrations (v1, v2, v3) of the polyene chain of xanthomonadin is 1004 (v3), 1136 (v2), 1529 (v1), 2267 (2v2), and 2656 (v1+ v2). Raman fingerprints of Xanthomonas spp. were compared with representative strains of numerous other bacterial genera including Agrobacterium, Bacillus, Clavibacter, Enterobacter, Erwinia, Microbacterium, Paenibacillus, and Ralstonia, which confirmed that that the Raman marker for xanthomonadin is a unique Raman marker for the genus Xanthomonas. Resonance Raman spectroscopic studies also characterized numerous bacteria with carotenoid pigments associated with the guttation fluid of anthurium plants and lives in close association with the plant pathogenic bacteria Xanthomonas axonopodis pv. dieffenbachiae, which causes bacterial blight of Anthurium.

8367-03, Session 1

Implantable nanobiosensor for real-time and continuous glucose monitoring

M. El Dweik, Lincoln Univ. (United States)

Development of an in vivo optical sensor requires the utilization of Near Infra Red (NIR) fluorophores since these fluorophores can operate within the biological tissue window. The fluorophores, Alexa Fluor 750 (AF 750) and Alexa Fluor 680 (AF 680), are NIR fluorophores that were examined as potential fluorescence resonance energy transfer (FRET) dye pairs. AF 680 and AF 750 were conjugated to streptavaidin and biotin, respectively, and the percent energy was determined. Next, the dye pair was utilized in a competitive binding assay to detect glucose. Concanavalin A (Con A) has an affinity to dextran, but in the presence of glucose, Con A will bind to glucose. This protein and inhibitor system is utilized as a glucose biosensor. In this study, the effect of dextran size on FRET was examined in order to obtain optimal energy transfer. Dextran with molecular weights of 10,000 and 3000 and Con A were labeled with AF680 and AF750 respectively, and incubated to form the dextran/Con A complex. The percent energy transfer was then obtained upon exposure to glucose. The experiments revealed that dextran with molecular weights of 10,000 demonstrated the highest energy transfer in responding to glucose between 3.33 and 13.29 mM. In conclusion, the NIR pair of AF 680 and AF750 was a viable FRET pair that can be utilized to determine glucose via a competitive binding assay of dextran (10,000) and Con A. These results will help improve the development of FRET based optical glucose biosensors

8367-04, Session 1

In vitro quantitation of human femoral artery atherosclerosis using near-infrared Raman spectroscopy

A. C. Dykes, S. K. Sharma, J. S. Allen III, P. Anastasiadis, Univ. of Hawai'i (United States)

Near-infrared Raman spectroscopy has been used in vitro to identify calcified atherosclerotic plaques in human femoral arteries. Raman techniques allows for the identification of these plaques in a nondestructive manner, which may allow for the diagnosis of coronary artery disease in cardiac patients in the future. As Raman spectroscopy also reveals chemical information about the composition of the arteries, it can also be used as a prognostic tool. The in vivo detection of atherosclerotic plaques at risk for rupture in cardiac patients will enhance treatment methods while improving clinical outcomes for these procedures. Raman spectra were excited by an Invictus 785-nm NIR laser and measured with a fiber-coupled micro-Raman RXN system (Kaiser Optical Systems, Inc., Ann Arbor, MI) equipped with a785 nm CW laser and CCD detector. Chemical mapping of arteries obtained post mortem allowed for the discrete location of atherosclerotic plaques. Raman peaks at 961 and 1073 cm-1 reveal the presence of calcium hydroxyapatite and carbonate apatite, which are known to be present in calcified plaques. By mapping the locations of these peaks the boundaries of the plaques can be precisely determined. Areas of varying degrees of calcification were also identified. Since this can be useful in

determining the degree of plaque calcification and vessel stenosis, this may have a significant impact on the clinical treatment of atherosclerotic plaques in the future.

8367-05, Session 2

Nondestructive imaging of stem cell in 3D scaffold

C. Chen, A. Yeatts, J. Fisher, Y. Chen, Univ. of Maryland, College Park (United States)

Fluorescence laminar optical tomography (FLOT) uses multiple detectors to achieve depth-resolved information through image reconstruction, typically yielding 100-200 micron resolution and 2-3mm penetration depth. In this work, we introduced the additional angular degree of freedom, namely the incidence and detection angle. Vast simulation and experiment studies of our second-generation angle FLOT (aFLOT) system have been performed, including singular value analysis, the effect of scattering on sensitivity and penetration depth, resolving capillary tube, acquiring point spread function (PSF) through imaging microbead, and 3D human mesenchymal stem cell (hMSC) distribution. We were able to resolve the hMSC distribution deep to 2.7mm repetitively.

8367-06, Session 2

Determination of potential multiphoton photoacoustic spectral signatures and characterization of a novel NMPPAS probe

S. Dahal, B. M. Cullum, Univ. of Maryland, Baltimore County (United States)

Multiphoton photoacoustic spectroscopy is a powerful technique for non-invasive or minimally invasive tumor differentiation and has a great potential to be used for optical biopsy in hospitals. It has been shown that, using the technique, excised brain tumor (grade III astrocytoma) can be distinguished from healthy brain tissue with 99% accuracy. Our research focuses on characterizing a portable fiber optic probe for sample excitation and signal collection, as well as identifying potential spectral signatures of multiphoton photoacoustic spectra obtained from tissues.

The probe was designed for flexibility in clinical setting to scan large areas of the suspected tissue in a short period of time. Optical fibers are used as the light transfer media from the laser source to the probe, and factors such as length and width of the fiber which affect the intensity and coherency of the laser, thus affecting the multiphoton excitation process, have been studied. Additionally, penetration depth studies in tissue phantoms have been performed with model chemical species to determine the maximum depth capable of being analyzed. In addition to charactering the probe, this talk will also discuss potential spectral signatures in multiphoton photoacoustic spectra as a result of various endogenous species found in the tissues, such as NAD+, NADH, collagen, elastin, porphyrin, etc.

8367-07, Session 2

Needle-based optical coherence tomography microendoscopy for deep brain imaging

C. Liang, J. Wierwille, Univ. of Maryland, College Park (United States); T. Moreira, G. Schwartzbrauer, M. S. Jafri, C. Tang, Univ. of Maryland School of Medicine (United States); Y. Chen, Univ. of Maryland, College Park (United States)

Endoscopic optical coherence tomography (OCT) is a promising minimally-invasive imaging technology for guiding the delivery of therapeutic devices or agents to deep brain regions. However, side-viewing OCT probes that have been demonstrated for neurosurgical guidance cannot avoid one of the most worried brain surgery side effects, cerebral hemorrhage. Therefore, developing a small-diameter, forward-imaging probe for detecting at-risk vessels in front of the surgical instrument is a critical and unmet challenge. We have developed an OCT forward-imaging needle (740 um O.D.) using gradient-index (GRIN) rod lens for guiding brain surgery and detecting at-risk vessels in real time. This needle-imaging probe provided high-speed (100 frames/s) and high-sensitivity (>90 dB) imaging of biological tissues with 13 um resolution. The potential of neurosurgical guidance was demonstrated on imaging human brain tissue ex vivo. The unique composition of gray and white matters in different brain compartments provides distinctive OCT landmarks for identifying whether the probe reaches the target site. The vessel detection capability of this imaging needle was demonstrated on sheep brain in vivo. The subsurface brain vessels in front of needle were detected by Doppler OCT (DOCT) in real time (8 frames/s). Our results suggested this OCT forward-imaging needle can potentially guide neurosurgery and reduce the risk of cerebral hemorrhage.

8367-08, Session 2

Quantitative evaluation of mucosal vascular contrast in narrow band imaging using Monte Carlo modeling

D. Le, The Catholic Univ. of America (United States) and U.S Food and Drug Administration (United States); Q. Wang, U.S. Food and Drug Administration (United States); J. C. Ramella-Roman, The Catholic Univ. of America (United States); J. Pfefer, U.S. Food and Drug Administration (United States)

Narrow-band imaging (NBI) is a spectrally-selective reflectance imaging technique for enhancing visualization of superficial vasculature. Prior clinical studies have indicated NBI's potential for facilitating detection of vasculature indicative of gastrointestinal mucosal neoplasia. While the basic mechanisms behind this technique - vessel contrast variations due to hemoglobin absorption and tissue scattering - are known, a quantitative understanding of the effect of tissue and device parameters has not been achieved. In this study, we developed and implemented a numerical model of light propagation that simulates NBI reflectance distributions. This was accomplished by incorporating mucosal tissue layers and vessel-like structures in a voxel-based Monte Carlo algorithm. Epithelial and mucosal layers as well as blood vessels were defined using wavelength-specific optical properties. The model was implemented to calculate reflectance distributions and vessel contrast values as a function of vessel depth (0.05 to 0.50 mm) and diameter (0.01 to 0.10 mm). These relationships were determined for NBI wavelengths of 410 nm and 540 nm, as well as a broadband illumination scenario that simulated standard endoscopic imaging. The effects of numerical aperture and illumination bandwidth on vessel contrast were also investigated. Our results provide a quantitative analysis of the effect of absorption and scattering on vessel contrast. Additional insights and potential approaches for improving NBI system contrast are also discussed.

8367-09, Session 2

Computer-aided diagnosis of masses and non-masses in breast MRI

A. D. Meyer Baese, The Florida State Univ. (United States)

Computer-Aided-Diagnosis of small masses and non-masses represents one of the most challenging topics in breast MRI due to their temporal and morphological characteristics.

The present paper proposes a novel approach to automatic lesion segmentation, feature extraction and classification based on intelligent systems taking into account both temporal and spatial characteristics. Krawtchouk moments are known for their descriptive power for local shape variations as it is the case with small irregular masses while Zernike moments for capturing architecture irregularities and blurred margins observed in non-masses. We employ problem-designed shape descriptors for local shape variations and irregular and blurred margins and evaluate them either solely or jointly and a subsequent classification system determines the discriminative performance between benign and malignant lesions.

The combined spatio-temporal classification based on a hierarchical intelligent systems yields the best results in terms of diagnosis.

8367-10, Session 3

Fabrication of microfluidic vascular phantoms by laser micromachining

S. A. Mathews, J. C. Ramella-Roman, L. Luu, The Catholic Univ. of America (United States)

Imaging of capillary structures and monitoring of blood flow within vasculature is becoming more frequent clinically. Yet very few dynamic phantoms exist mimicking capillary structures. We report the fabrication and testing of microfluidic, vascular phantoms aimed at the study of blood flow. These phantoms are fabricated using low-cost, off-the-shelf materials and require no lithographic processing, stamping, or embossing. Using laser micromachining, complex microfluidic structures can be fabricated in under an hour. The laser system is capable of producing microfluidic features with sizes on the order of tens of microns, over an area of several square centimeters. Because the laser micromachining system is computer controlled and accepts both vector and raster files, the microfluidic structure can be simple, rectilinear patterns or complex, anatomically correct patterns. The microfluidic devices interface with simple off the shelf syringe pumps. The microfluidic devices were used for non invasive monitoring of flow using speckle based techniques and RBC tracking techniques.

8367-11, Session 3

Development of microLIPS: a novel microfluidic assay for rapid serum antibody detection

M. Chandrangsu, P. D. Burbelo, A. Zubair, R. Wilson, M. J. Iadarola, P. D. Smith, N. Y. Morgan, National Institutes of Health (United States)

There is considerable interest in the development of rapid, point-of-care antibody detection for the diagnosis of infectious and auto-immune diseases. We present work on the development of a self-contained microfluidic format for the Luciferase Immunoprecipitation Systems (LIPS) assay. Whereas the majority of immunoassays for antigen-specific antibodies employ either bacteria- or yeast-expressed proteins and require the use of secondary antibodies, the LIPS technique uses a fusion protein comprised of a Renilla luciferase reporter and the antigen of interest produced via mammalian cell culture, ensuring the addition of mammalian post-translational modifications. Patient serum is mixed with the fusion protein and passed over immobilized Protein A/G; after washing, the only remaining luciferase-tagged antigens are those retained by specific antibodies. These can be quantitatively measured using chemiluminescence upon the introduction of coelenterazine. The assay has been successfully employed for a wide variety of diseases in a microwell format. We report on a recent demonstration of rapid HSV-2 diagnosis with the LIPS assay in a microfluidic format, using one microliter of serum and obtaining results in under ten minutes. We will also discuss recent progress on two fronts, both aimed at the deployment of this technology in the field: first, simplifying assay operation through the automation of flow control using power-free means; and second, efforts to increase signal levels, primarily through strategies to increase antibody binding capacity, in order to move towards portable battery powered electronics.

8367-12, Session 3

Lab-on-a-chip platforms from sample preparation via continuous-flow PCR to an ultrafast detection of B-agents

C. Gärtner, H. Becker, microfluidic ChipShop GmbH (Germany); N. Hlawatsch, R. Klemm, microfluidic ChipShop GmbH (United States); T. Clemens, CLEMENS GmbH (Germany)

The focus is the realization of a reliable, ultrafast, and portable tool for the identification of B-agents at the point of interest. For the doubtless identification of B-agents on nucleic acid level a PCR based detection assay will be used. The overall function of the system covers sample preparation starting with the lysis of the bacterial pathogens and followed by the DNA extraction. The cleaned DNA will be transferred in the amplification area in order to multiply the target DNA. In parallel an optical detection is carried out.

To enable not only the integration of all the above mentioned process steps but also to realize a portable system, miniaturization is applied. The overall system consists of the Lab-on-a-Chip unit as consumable device, and an instrument to control the liquid and thermal management of the Lab-on-a-Chip device as well as the detection.

The novel PCR concept working with fixed temperature zones in the instrument and arranging the thermal cycling via moving the sample over the temperature zones of the instruments, reduces the power consumption via avoiding the thermal cycling of the instrument. Thus, combining miniaturization with avoiding thermal cycling leads to a portable instrument.

A sample-in-result-out lab-on-a-chip device allowing for running eight different amplification reactions from one sample in parallel will be presented. Analytical results Typical B-agents like e.g. target pathogens, Francisella tularensis, Burkholderia mallei, Burkholderia pseudomallei, Brucella melitensis, Brucella abortis, and Coxiella burnetii will be shown.

8367-13, Session 3

Automated and miniaturized detection of biological threats with a centrifugal microfluidic system

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The world's growing mobility, mass tourism and also possible acts of terrorism, increase the risk of a fast distribution of infectious microorganisms and toxins. Hence, a robust and mobile field diagnostic system is required. Presented are (i) a microstructured test carrier enabling complex biochemical analysis, (ii) a mobile centrifugal microfluidc platform to perform fully automated liquid handling on a test carrier, and (iii) a simple on-disc reagent storage concept enabling the time-controlled release of liquids to process bioanalytical assays. This system promises robust and automated field testing for biological threats.

(i) A novel process that enables the production of microfluidic test carriers from a polymer film has already been reported for sensitive subtyping of pathogenic bacteria by real-time PCR and isothermal analysis. A detection limit of < 10 copies in a time < 15 minutes could be achieved for the isothermal detection.

(ii) The test carriers for this assay are fully automated by microfluidic integration and processed by a centrifugal device. The operator does not require any expert-knowledge in liquid handling or laboratory work. A fully automated and defined frequency and temperature protocol runs to process the complete assay.

(iii) The disposable test cartridge features a pre-storage containing the necessary liquids and dry reagents for the reaction. Test carriers for the detection of toxins such as ricin and botulinum as well as test carries for the detection of pathogenic bacteria and viruses such as B. anthracis and Y. pestis are currently being developed.

8367-14, Session 3

Rapid identification of Yersinia pestis and Brucella melitensis by chip based continuous flow PCR

M. Dietzsch, Friedrich-Loeffler-Institut (Germany); N. Hlawatsch, microfluidic ChipShop GmbH (Germany); F. Melzer, H. Tomaso, Friedrich-Loeffler-Institut (Germany); C. Gärtner, microfluidic ChipShop GmbH (Germany); H. Neubauer, Friedrich-Loeffler-Institut (Germany)

To combat the threat of biological agents like Yersinia pestis and Brucella melitensis in bioterroristic scenarios requires fast, easy-to-use and safe identification systems. In this study we describe a system for rapid amplification of specific genetic markers for the identification of Yersinia pestis and Brucella melitensis. Using chip based PCR and continuous flow technology we were able to amplify the targets simultaneously with a 2-step reaction profile within 20 minutes. The subsequent analysis of amplified fragments by standard gel electrophoresis requires another 45 minutes. We were able to detect both pathogens within 75 minutes being much faster than most other nucleic acid amplification technologies.

8367-15, Session 3

Automated DNA-preparation system for bacteria out of air sampler liquids

R. Gransee, K. S. Drese, M. Ritzi-Lehnert, Institut für Mikrotechnik Mainz GmbH (Germany); C. Disque, Molzym GmbH Co. KG (Germany); G. Zoll, Wehrwissenschaftliches Institut für Schutztechnologien (Germany)

Possible bacterial contaminations can be a huge problem in different fields ranging from food industries to life science applications or the detection of biological warfare agents. We present an automated lab-on-a-chip system which is capable of extracting bacteria out of liquid samples and the subsequent purification of their DNA. It enables the capture and lyses of germs and the following binding, washing and eluting steps of the therefore purified DNA.

The whole process happens wholly automated, starting with the loading of the 10 ml sample into the disposable chip up to the generation of 120 µl DNA elution for further analysis, therefore enabling both up concentration of bacteria out of a high volume sample and purification of bacteria DNA. The system comprises a polymer chip that contains filters, mixings structures, turning valves, optical detection structures, a DNA binding matrix and buffer reservoirs with stored liquids. The chip is manufactured by injection molding with subsequent assembly steps. The instrument consists of syringe pumps for liquid transport inside the chip system, motors for valve actuation, heaters with temperature sensors and optical devices for detecting the position of the sample plug inside the chip system. A proof of concept has been achieved showing the successful detection of DNA from captured E. coli BL21 bacteria.

8367-16, Poster Session

Development and testing of a fluorescence biosensor for continuous glucose sensing

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Fluorescence-based biosensors have been reported to be useful as continuous glucose monitoring systems. Such rapid and accurate continuous monitors have the potential to enhance glucose management for individuals with diabetes mellitus and improve the outcome of critically ill patients in intensive care settings, including those without diabetes. Recent studies have indicated that implantable biosensors based on Förster Resonance Energy Transfer (FRET) can provide high sensitivity in quantifying glucose concentrations. However, standard approaches for determining chemical specificity have not been established. The aim of this work was to optimize the design of a FRET-based glucose sensor and evaluate its specificity for sensing glucose over other sugars. A sensor using the competitive binding approach between concanavalin A (Con A) and dextran, labeled with long-wavelength acceptor and donor fluorophores, was developed. This process included optimization of dextran molecular weight and concentration, acceptor to donor ratio, and hydrogel concentration, as well as the number of polymer layers for encapsulation. The effect of various sugars including, mono- and di-saccharides was examined and a criterion for interference detection developed. Time response in the presence of glucose and the effect of glucose concentration on response were also analyzed. The resulting FRET-based sensor maximizes the signal-to-background ratio and change in signal in response to glucose, minimizes aggregation, and maximizes the dynamic range and sensitivity to clinically relevant high and low glucose concentrations.

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8368-01, Session 1

Optical design considerations for both automotive and aerospace environment

S. Thibault, Univ. Laval (Canada)

Making a lens design working in automotive environment is a real challenge. Both optical and mechanical designer must work together to prevent problems during operation. The increasing trend to use vision sensors in transportation is driven both by legislation and consumer demands for higher safety and better driving experiences. With the demand, many new material and design techniques have been developed increasing the lens designer toolbox. This paper reviews the design constraints of the automotive and aerospace environment and how modern material, tools and approaches can be used to fulfill it. We discussed a particular trade-off between the uses of plastic and glass optical component. We also discussed the impact of vision system which is outside or inside the vehicle regarding design trades and performances within the environmental constraints.

8368-02, Session 1

Broad area optical debris impact sensor

L. R. Gauthier, Jr., M. E. Jansen, J. R. Meyer, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Fiber optic sensors offer many advantages over electrical sensors for use in harsh environments. One advantage over distributed electrical sensors is the elimination of the need to route electrical power and wiring to the sensors, which, in general improves safety and reduces power consumption. Another advantage is that the optical sensors are immune to electromagnetic interference that may be caused by radio frequency signals used for communications. Another benefit of using an optical approach for impact detectors is the implicit immunity from false detections that may otherwise be caused by unrelated mechanical shock or vibration events. Previous studies have documented the characteristics of the Optical Debris Impact Sensor (ODIS). With ODIS, the impacts are inferred by detecting the brief triboluminescent optical pulses that are generated by the abrupt charge separation within a phosphor that is caused by the particle impacts. The main limitations of ODIS were the small detection area and the limited sensitivity. This paper describes a method for extending the ODIS sensor to accomplish broad area detection on a surface with potentially higher sensitivity. The sensing element is comprised of a stack of planar optical waveguides with phosphor-coated strips. The geometry of the design ensures that optical pulses are automatically captured by the waveguides and routed to a fiber optic cable that transports the signal to a remote high speed photo-detector. Background light levels in the vicinity of the detector are filtered out by the tailored frequency response of the photo-detector.

8368-03, Session 1

A fiber optic sensor for hydrogen detection: surface plasmon resonance sensor based on wavelength modulation

N. Javahiraly, C. Perrotton, P. P. Meyrueis, Ecole Nationale Supérieure de Physique de Strasbourg (France); M. Slaman, B. Dam, Technische Univ. Delft (Netherlands)

A new design of a fiber optic sensor using Palladium as a sensitive layer is presented. In this new configuration, a transducer layer is deposited on a multimode fiber (without the optical cladding). The transducer layer is a multilayer stack based on a silver, a silica and a Pd layer.

The spectral modulation of the light transmitted by the fiber allows to detect hydrogen. The sensor is only sensitive to the Transverse Magnetic polarized light and the Transverse Electric polarized light can be used as a reference signal.

The multilayer thickness defines the sensor performance. The Silica thickness tunes the resonant wavelength, whereas the silver and Pd thickness determines the sensor sensitivity. The resonant wavelength is shifted over 17,6 nm at a concentration of 4 % hydrogen in argon for the design of the 35 nm silver/ 100 nm silica/ 3 nm Pd multilayer.

Keywords: fiber optic sensor, hydrogen detection, metal hybride.

8368-04, Session 1

Optical hydrogen sensors based on metal-hydrides

M. Slaman, Technische Univ. Delft (Netherlands)

For many applications optical hydrogen sensors are preferred above electrical systems. Optical sensors reduce the risk of ignition by spark formation. Currently, palladium and palladium alloys are used for most hydrogen sensors. The disadvantages of palladium in sensors are the low optical response upon hydrogen loading, the cross sensitivity for oxygen and carbon, the limited detection range and the formation of micro-cracks after some hydrogen absorption/desorption cycles.

We have found that the use of magnesium or rare earth based metal-hydrides in optical hydrogen sensors allow tuning of the detection levels over a broad pressure range. We have demonstrated a stable detection layer for detecting hydrogen below 10% of the lower explosion limit in an oxygen rich environment. This detection layer is deposited at the bare end of a glass fiber as a micro-mirror and is covered with a thin layer of palladium. The palladium layer promotes the hydrogen uptake at room temperature and acts as a hydrogen selective membrane. To protect the sensor for a long time in air a protection layer of a hydrophobic fluorine based coating is applied.

Recently, we found that this type of fiber optic hydrogen sensor is also suitable for hydrogen detection in liquids. As example we have demonstrated a sensor detecting a broad range of hydrogen concentrations in transformer oil. Such a sensor can signal a warning when sparks inside a high voltage power transformer decompose the transformer oil, which might result in the explosion and destruction of the transformer.

8368-05, Session 1

Fiber optic oxygen sensor using fluorescence quenching for aerospace application

A. S. Panahi, H2Scan (United States)

In this paper we explore Fluorescence Technology as applied to the design and development of O_2 sensors that can be used for this application and discuss the various test and measurement techniques used to estimate the O_2 gas concentration. Jet fuel comprised of heavier hydrocarbon components is much less volatile, than jet fuel having a flash point of approximately 37° C and JP-4 having a flash point of approximately -17° C. In contrast, straight-run gasoline has a flash point of approximately -40° C. The flash point is the minimum temperature where a liquid fuel can generate enough vapor to form a flammable mixture with air. If the temperature is below the flash point there isn't enough fuel evaporating to form a flammable fuel-air mixture. Since jet

fuel and gasoline have similar flammable concentration limits, gasoline must produce much more vapor at a given temperature to have such a low flash point; hence gasoline is much more volatile than jet fuel. We compare the various intensity based approaches and contrast them with the frequency domain techniques that measure phase to extract fluorescent lifetimes. An innovate compact measurement system using the frequency heterodyning cross correlation technique that can be used for various applications is described in detail while the benefits are explored together with some test data collected. The various inerting fuel tank requirements are explained.

8368-06, Session 2

Plastic optical fiber hydrogen detection sensor systems for harsh environment in aerospace application

A. A. Kazemi, The Boeing Co. (United States); E. A. Mendoza, Redondo Optics, Inc. (United States); K. Goswami, InnoSense LLC (United States); L. U. Kempen, Institut Mess- und Sensortechnik (Germany)

This paper describes the successful Plastic Optical Fiber (POF) hydrogen detection sensor systems developed for the Boeing Delta IV Launch Vehicle harsh environment of engine section. H2 sensors are necessary to monitor the possible leak of rocket prior launch to avoid explosion, which can be highly dangerous. Due to very harsh environment of launch vehicle, we developed the first 100 m POF H2 sensors. The hydrogen sensor consisted of optrodes distributed at multiple locations along a fiber optic cable-based network. The hydrogen sensors were used on the Common Booster Core (CBC) of Delta IV had to perform in temperatures between -17° C and +60° C. The hydrogen sensor sensitive chemistry was fully reversible and had demonstrated a response to hydrogen gas in the range of 0% to 10% with a resolution of 0.1 % and a response time of 5 seconds measured at a gas flow rate of 1 cc/mm. The optical signature of the optrode in the visible spectrum varied proportionally to the local hydrogen gas concentration. To qualify the POF and glass cables, performed detail investigation of POF + glass cables for attenuation loss, tension, bend, thermal, humidity, temperature, vibration and accelerate testing for life expectancy. Also evaluated performance of POF and glass cables for absorption, insertion loss, return loss, and harsh environmental. Extensive networking using MatLab were carried out for lab and actual field demonstrations.

8368-07, Session 2

Compact fiber Bragg grating sensor system and its potential for aircraft health monitoring

N. Mrad, Defence Research and Development Canada, Ottawa (Canada)

Commercial and military aircraft operators and are faced with the challenge of reducing operation and maintenance cost, while increasing aircraft safety and reliability. The concept of structural health monitoring (SHM) has emerged as a potential approach to this challenge and as an alternative to the current conventional complex and cost ineffective methods. Among a wide range of SHM techniques, fiber Bragg grating (FBG) sensor and sensor systems have shown great potential in this field due to the unique advantages, such as light weight, small size, immunity to electromagnetic interference, high multiplexing capability, etc. However, one of the limitations for the implementation of fiber optic based SHM systems within an aircraft is the lack of suitable interrogation device, which is used to decode and analyze the feedback signal from FBG sensors and evaluate the structural status of the aircraft. In addition to the stringent performance requirements, implementations require the sensor interrogation device to be compact, light weight and robust. Recent development of FBG sensors has proved that these sensors are able to be used for operational load monitoring and impact damage detection, the two major aspects of aircraft SHM applications. To address some the identified challenges, we have initiated the development of compact FBG sensor interrogation devices based on planar lightwave circuits (PLC). In this paper, we summarize the design and development of this type of sensing systems and discuss their potential applications to the structural health monitoring of aircraft

8368-08, Session 2

Challenges for developing low-cost plastic optical fiber (POF) networks for avionics applications

E. Y. Chan, A. A. Kazemi, D. G. Koshinz, The Boeing Co. (United States)

Recently there has been strong interest in developing plastic optical fiber (POF) networks for avionics platforms. POF has large (1 mm) diameter, high durability to bending and breakage. POF is low cost because of its connector termination simplicity and the economy of scale due to its deployment in the automobile applications. There are many challenges to transition the POF technology from automobile applications to avionics platforms. This paper will address some of theses challenges due to POF attenuation, stringent POF transceiver, high port court POF star couplers, termini, cables and connectors requirements for aerospace applications. Future development in the POF component technology will be discussed.

8368-09, Session 2

Response comparison of two FBG-based hydrophones

I. F. Saxena, Intelligent Optical Systems, Inc. (United States)

Fiber optic hydrophones remain of great interest for a variety of sound monitoring applications. Methods used for fiber sensor packaging and mounting offer differences in sensitivity and frequency responses which can be optimized for specific applications. Two ways of packaging fiber hydrophone sensor heads based on fiber bragg gratings are described. Acoustic responses are measured using spectral domain detection and the response characteristics are compared. Resistance to temperature variation is also discussed.

8368-10, Session 3

Optical embedded dust sensor for engine protection and early warning on M1 Abrams/ ground combat vehicles

H. Lin, Intelligent Optical Systems, Inc. (United States); G. A. Waldherr, Hal Technology, LLC (United States)

A miniature dual optical embedded dust sensor (DOEDS) is designed for sensitive, accurate detection of particles in a harsh environment for preventive monitoring of the M1 Abrams AGT1500 engine and engines on ground combat vehicles (GCVs) and helicopters. Military turbine engines with large intake air flow rates are easily exposed to dust and particle contamination. Exposure leads to compressor/turbine blade erosion, reduced efficiency and ultimately to engine failures. Lack of detection leads to premature wear, increased maintenance time, cost, and failure of engine components.

The DOEDS is a real-time sensor that uses a combination of optical particle sensing technologies and mechanical packaging in a rugged, compact and non-intrusive optical design. The DOEDS dual optical sensor implements an optical particle sensor and an optical mass sensor to meet the particle size, size distribution, mass concentration, and response time criteria. An advantage of our optical sensor is the ability to operate in a harsh environment where the temperature could reach up to 400°F, shock up to 75 g at 0.5 ms (half sine) and vibration up to 4 g

sine to 500 Hz at 180 minutes/axis. The DOEDS will have the sensitivity and dynamic range to detect a single 1 micron dust particle up to 1,000,000 particles per cubic foot or more, and will quantify particle size distributions between 1 and 200 microns to help diagnose root causes for dust ingestion (air filter failure or engine seal failure). The sensor may be flush or inline mounted in multiple engine locations and environments.

8368-11, Session 3

Miniature multi-analyte fiber-optic sensor probe

L. U. Kempen, Intelligent Optical Systems, Inc. (United States)

A miniature fiber-optic chemical sensor system allowing for simultaneous detection of gas concentrations and physical parameters is described, fabricated and tested. The design is focused on minimizing influence of the sensor onto the system under test, therefore employing very thin and pliable fiber probes. Microfabrication of the sensor structure is described and a suitable interrogation setup is introduced. Measurements of O2 and CO2 concentrations are presented and discussed. Applications in continuous medical monitoring and necessary design and operating parameters are described.

8368-12, Session 3

Comparative spectral analysis of commercial fuel-ethanol blends using a low-cost prototype FT-Raman spectrometer

V. Ortega Clavero, A. Weber, W. W. Schröder, Hochschule Offenburg (Germany); P. P. Meyrueis, N. Javahiraly, Univ. de Strasbourg (France)

The use of bio-fuels and fuel blends, specially in automotive ndustry, has been increasing substantially in recent years due to market prices and trends on sustainable development policies. Different spectral analysis techniques for quality control, production, purity, and counterfeit detection have been reported as non-invasive, fast, and price accessible.

Raman spectra from three different commercial binary fuel-ethanol blends has been obtained by using a low-cost Fourier-Transform Raman spectrometer (FT-Raman). Comparisons between the commercial fuel blends and laboratory-prepared fuel blends have been perform. The spectral information is presented in the range of 0 cm−1 to 3500 cm−1 with a resolution of 1.66 cm−1 , and with reduced spectral deviation compared to theoretical values (less than 0.4 cm−1 without compensation for instrumental response). Higher resolution values are possible, since the greater optical path lengths of the FT-Raman are achievable before the instrumental physical effects appear.

The robust and highly flexible FT-Raman prototype proposed for the spectral analysis, consisting mainly of a Michelson interferometer and a self-designed photon counter, is able to deliver high resolution and precise Raman spectra with no additional complex hardware or software control. The mechanical and thermal disturbances affecting the FT-Raman system are mathematically compensated by extracting the optical path information from the generated interference pattern of a λ = 632.8 nm Helium-Neon laser (HeNe aser), which is used at the spectrum evaluation.

8368-13, Session 3

Aircraft fiber optic structural health monitoring

N. Mrad, Defence Research and Development Canada, Ottawa (Canada)

Structural Health Monitoring (SHM) is a sought after concept that is expected to advance military maintenance programs, increase operational safety and reduce life cycle cost. Such concept is further considered to constitute a major building block of any Integrated Health management (IHM) capability. Since 65% to 80% of military assets' Life Cycle Cost (LCC) is devoted to operations and support, the aerospace industry and the military sectors continue to look for opportunities to exploit SHM systems, capability and tools. Over the past several years, countless SHM concepts and technologies have emerged. Among those, fiber optics sensor and sensor systems are identified of significant potential particular in the aerospace sector.

For the past decade Defence R&D Canada has been developing SHM related technologies and capability including the development, evaluation and demonstration of Fiber Bragg Gratings (FBG) based SHM. This paper discusses such efforts and provides the state of development of fiber optic sensors and sensors interrogation systems for the potential implementation in an aircraft (e.g. the CF-18 Hornet). Full scale representative technology and experimental evolution is also presented.

8368-14, Session 3

Next generation specialty optical fibres for harsh environment applications: challenges, advancements and opportunities

S. Rehman, Fibertronix AB (Sweden)

The monitoring of civil structures using fibre-optics sensor systems can provide timely, predictive information for the assets management. A key enabling technology-to make fibre sensors rugged and reliable for such applications-has been the use of specialty optical fibers. However, given some of the recently trends, higher operating temperatures, tight bends, measurement of new physical parameters such as sound and vibration-new demands are being put on optical fiber sensors which will require a new generation of customized, specialty optical fiber. This paper will review the application needs and their associated technical challenges, advancements and opportunities for future civil structure monitoring applications.

8368-15, Session 4

Cross-link space-based laser systems for satellite communications

A. A. Kazemi, The Boeing Co. (United States); A. S. Panahi, ARK International (United States)

In this paper we will focus on the requirements of the space-based lasers and optics used for beam forming, as well as receiver antenna gain and detectors used in free space communications. Space-based optical communications using satellites in low earth orbit (LEO) and Geo synchronous orbits (GEO) hold great promise for the proposed Internet in the Sky network of the future. Building high speed communications network using optical links in space has proven to be an extremely complicated task and many such schemes were tried without success in the past. However in the last few years, there has been impressive progress made to bring the concept to fruition in civilian and government-non classified projects. Laser Communications High data rate, small antenna size, narrow beam divergence, and a narrow field of view are characteristics of laser communications that offer a number of potential advantages for system design. Space-based optical communications using satellites in low earth orbit (LEO) and Geo-synchronous orbits (GEO) hold great promise for the proposed Internet in the Sky network of the future. Also discussed are the critical parameters in the transmitter, channel, receiver, and link budget that are employed in successful inter-satellite communications system. We cover that Laser Communications offer a viable alternative to established RF communications for inter-satellite links and other applications where high performance links are a necessity.

8368-16, Session 4

Development of an in-situ wireless strain monitoring system and its integration with FEA SHM simulation models

F. Abdi, AlphaSTAR Corp. (United States)

The paper proposes the development and verification of a hardware and software tool that will be able to evaluate and optimize sensorized aerospace structures. The tool will be extension of an existing suite of structural health monitoring (SHM) and diagnostic prognostic system (DPS). The goal of the extended SHM-DPS is to apply multi-scale nonlinear physics-based finite element analyses to the "as-is" structural configuration to determine residual strength, remaining service life, and future inspection intervals and procedures. Information from a distributed system of sensors will be used to determine the "as-is' state of the structure versus the "as-designed" target. The proposed approach will enable active monitoring of aerospace structural component performance and realization of DPS-based maintenance. Software enhancements will incorporate information from a sensor system that is distributed over an aerospace structural component. In the case of the proposed project, the component will be a stiffened composite fuselage panel. Two stiffened panels is instrumented with wireless sensors; the second with an optimized sensor network. It is shown that the sensor system output will be routed and integrated into a nonlinear multi-scale physics-based finite element analysis (FEA) tool to determine the panel's residual strength, remaining service life, and future inspection interval. The FEA will utilize the GENOA progressive failure analysis software suite, which is applicable to metallic and advanced composites.

8368-17, Session 5

Content-dependent, on-the-fly visual information fusion for battlefield scenarios

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We report on cooperative research program between Army Research Laboratory (ARL), Night Vision and Electronic Sensors Directorate (NVESD), and University of Maryland (UMD). The program aims to develop advanced on-the-fly atmospheric image processing techniques based on local information fusion from a single or multiple monochrome and color live video streams captured by imaging sensors in combat or reconnaissance situations. Local information fusion can be based on various local metrics including local image quality, local image-area motion, spatio-temporal characteristics of image content, etc. Tools developed in this program are used to identify and fuse critical information to enhance target identification and situational understanding in conditions of severe atmospheric turbulence.

8368-18, Session 5

Structured IR illumination for relative depth sensing in virtual interface in transportation

B. C. Kress, V. Hejmadi, USI Photonics Inc. (United States)

Structured illumination for gesture sensing and 3d mapping has been used by many industries ranging from consumer electronics to surgery and automotive. Such laser structured illumination systems are usually based on diffractive optics and project in the far field line or spot structures.

Most of these sensing systems are designed for absolute depth mapping, which produces vast amounts of data to be processed, and results in a true 3D map. Such true 3D maps are very desirable for many applications, however not for gesture sensing in virtual interfaces such as the ones to be used in transportation (automotive, avionics, etc...).

Instead, for virtual interfaces gesture sensing, it is more interesting to sense relative depths at specific areas of interest, rather than take the true 3D picture of an entire field which also requires heavy data processing. For example our structured illumination sensor will be able process only relative distances from the hands to the virtual interface plane, or the relative distances from one hand to the other, of from the hand to a mechanical actuator, without processing any other optical information in the field.

In order to do this, we propose to use a novel type of IR laser structured illumination scheme.

The structured illumination scheme is described as well as the design and fabrication of the structured illumination devices and the data processing algorithm. A prototype has been fabricated and actual optical test results are shown on a typical virtula interface for the automotive industry.

8368-19, Session 5

Polarization based vision sensor for automotive

P. Desaulniers, S. Thibault, Univ. Laval (Canada)

The polarization state of light provides valuable information about scenes that cannot be obtained directly from intensity or spectral images. Polarized light reflected from scenes has been found to be useful and can reveal contrasts that do not appear in classical intensity images and find many applications in remote

sensing, biomedical imaging, or industrial control. Cost, size, and technological complexity of polarimetric imagers depend on the number of polarimetric parameters they measure. In this context, a key issue is to evaluate the added value of each measured polarimetric parameter in order to optimize the compromise between complexity and efficiency of these systems. In target detection applications, the relevant criterion for quantifying the performance of an imaging configuration is contrast (or discrimination ability). Analysis of the contrast and its optimization in polarimetric images have been investigated in the radar and optics communities. We investigate in the paper how the polarisation imaging can be applied in automotive vision based sensor. This study compared various type of polarisation sensitive optical system. Detection of small and low-contrast objects has been found to be improved with the help of this kind of optical system.

8368-20, Session 5

High temperature cycling resistant, epoxy-bonded FBG strain sensors on metal substrates

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Fiber optic strain sensing in adverse environments is attractive as there are several advantages. While epoxies are convenient to use for bonding fiber bragg gratings to metal substrates, operation at higher temperatures poses certain challenges. These challenges are outlined as well as possible methods to overcome them to obtain very low residual wavelength shifts upon bonding.

Methods for epoxy-bonding fiber bragg grating sensors to different metal substrates for high temperature operation are described, and results presented for a temperature cycling range of -40 to 125 C. Very low residual wavelength shifts with epoxy bonding are obtained.

8368-21, Session 5

Highly-hermetic feedthrough fiber pigtailed circular TO-can electro-optic sensor for avionics applications

J. Lauzon, L. Leduc, D. Bessette, N. Bélanger, Esterline CMC Electronics (Canada)

Electro-optic sensors made of lasers or photodetectors assemblies can be associated with a window interface. In order to use these sensors in an avionics application, this interface has to be set on the periphery of the aircraft. This creates constraints on both the position/access of the associated electronics circuit card and the aircraft fuselage. Using an optical fiber to guide the light signal to a sensor being situated inside the aircraft where electronics circuit cards are deployed is an obvious solution that can be readily available. Fiber collimators that adapt to circular TO-can type window sensors do exist. However, they are bulky, add weight to the sensor and necessitate regular maintenance of the optical interface since both the sensor window and the collimator end-face are unprotected against contamination. Such maintenance can be complex since the access to the electronics circuit card, where the sensor is sitting, is usually difficult. This interface alignment can also be affected by vibrations and mechanical shocks, thus impacting sensor performances.

As a solution to this problem, we propose a highly-hermetic feedthrough fiber pigtailed circular TO-can package. With the optical element to optical fiber interface being set inside the hermetic package, there is no risk of contamination and thus, such a component does not require any maintenance. Since the footprint of these sensors are identical to their windowed counterparts, they offer drop-in replacement opportunities. Moreover, we have validated such packaged electro-optic sensors can be made to operate between -55 to 115°C, sustain 250 temperature cycles, 1500G mechanical shocks, 20Grms random vibrations without any performance degradations. Their water content is much smaller than the 0.5% limit set by MIL-STD-883, Method 1018. They have also been verified to offer a fiber pigtail strain relief resistance over 400g. Depending on the electronics elements inside these sensors, they can be made to have a MTBF over 50 000h at 100°C.

8368-27, Session 5

Developing aircraft photonic networks for airplane systems

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Using high speed fiber optic communication networks for airplane systems has proved to be challenging and faces complex issues, especially in achieving affordable systems. In this paper we describe progress within the EU Framework 7 project DAPHNE (Developing Aircraft Photonic Networks) aimed at addressing these issues.

The aim of DAPHNE is to exploit photonic technology from terrestrial communications networks, and then develop and optimize aircraft photonic networks to take advantage of the potential cost savings. This is to be achieved through: multiplexing networks where possible; providing standard components for aircraft use; simplifying installation; and reducing through life support costs. The DAPHNE project started in September 2009 and will run until February 2013. The project has fifteen partners from seven nations and is supported by the European Commissions Seventh Framework Program (FP7).

The main advantages of photonic networks for aircraft systems are: reduced size & weight; enormous transmission bandwidth; and excellent Electromagnetic Compatibility (EMC) without heavy and bulky shielding. The purpose of this project is to maximize the benefits of the optical approach through network integration wherever possible. In addition, development has been undertaken on the adaptation of terrestrial components for use on aircraft with as little overhead as possible.

There are major differences between aircraft networks and terrestrial telecoms systems and other optical networks. Fewer nodes and shorter link lengths are required (meters rather than kilometers); multiple traffic types are utilized; signal speeds vary from sub-kbps to multi-Gbps; and analogue and digital signals are both employed. Furthermore, there are component limitations since aircraft systems demand extended environmental performance and component standards as a pre-requisite for component qualification with many aircraft manufacturers.

Up to date results on the progress of the DAPHNE project will be reported and, in particular, an overview of the demonstration systems to be established before the end of the project. These systems are being used to verify component and modeling design work undertaken during the project.

8368-22, Session 6

Optimal selection of fiber optic interconnection components and methods based on application, environment and use

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A fiber optic system can be designed, assembled and installed with many options for active and passive components and system elements. Interconnection systems should be designed with a detailed BOM, including fiber/cable, connectors, ruggedization materials and other passive components for the desired application. The selection of these items should be specific to the requirements of the system when considering environmental and mechanical limitations, and from the standpoint of the users who will be installing, maintaining and possibly repairing the system sometime in the future.

The paper will review various alternatives available when selecting components at design-in stage and discussing options for different scenarios of required optical performance. Considerations of component selection with regard to capabilities of the installers, maintenance and repair personnel and other key people who will be

responsible for the success of the system will also be discussed.

A fiber optic system when compared to an electrical system is not necessarily more difficult to install and maintain, but is different from electrical systems. As long as proper component selection is considered at the design stage and adequate skill levels

and training are planned, the fiber optic system should be successful.

8368-23, Session 6

Determination of solid materials rigidity modulus by a new nondestructive optical method: application to electrical steering system

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We propose a new non destructive optical method for the determination of the shear modulus G of solid materials. The shear modulus is determined by measuring the twisted angle as a response of the material sample, depending on an applied force. The measuring of this twisted angle is obtained by using an adapted polarimetric sensor. The effective measurement of rigidity modulus G for Aluminum, Plexiglas and Steel were experimentally achieved, we obtained respectively 1.4464.1010 N/m², 0.99417.109 N/m² and 1.0395.1011 N/m². The study has demonstrated the effective usefulness of our method for evaluating the rigidity modulus. A good agreement between the theoretical and experimental results was achieved.

8368-24, Session 6

Proven high-reliability assembly methods applied to avionics fiber-optics high-speed transceivers

J. Lauzon, L. Leduc, D. Bessette, N. Bélanger, R. Larose, B. Dion, Esterline CMC Electronics (Canada)

Harsh environment avionics applications require operating temperature ranges that can extend to, and exceed

-50 to 115°C. For obvious maintenance, management and cost arguments, product lifetimes as long as 20 years are also sought. This leads to mandatory long-term hermeticity that cannot be obtained with epoxy or silicone sealing; but only with glass seal or metal solder or brazing. A hermetic design can indirectly result in the required RF shielding of the component. For fiber-optics products, these specifications need to be compatible with the smallest possible size, weight and power consumption. The products also need to offer the best possible high-speed performances added to the known EMI immunity in the transmission lines.

Fiber-optics transceivers with data rates per fiber channel up to 10Gbps are now starting to be offered on the market for avionics applications. Some of them are being developed by companies involved in the "normal environment" telecommunications market that are trying to ruggedize their products packaging in order to diversify their customer base. Another approach, for which we will present detailed results, is to go back to the drawing boards and design a new product that is adapted to proven MIL-PRF-38534 high-reliability packaging assembly methods. These methods will lead to the introduction of additional requirements at the components level; such as long-term high-temperature resistance for the fiber-optic cables. We will compare both approaches and demonstrate the latter, associated with the redesign, is the preferable one.

The performance of the fiber-optic transceiver we have developed, in terms of qualification tests such as temperature cycling, constant acceleration, hermeticity, residual gaz analysis, operation under random vibration and mechanical shocks and accelerated lifetime tests will be presented. The tests are still under way, but so far, we have observed no performance degradation of such a product after more than 1050 hours of operation at 95°C.

8368-25, Session 6

Optical fiber sensing of corroded materials with evanescent wave absorption measurements

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This research effort is to demonstrate a remote sensing method using optical fibers with a Fourier Transform Infrared (FTIR) interferometer as an evanescent wave spectroscopic technique. In addition to the usual advantages of optical fiber sensors, such as small size and weight, optical fibers can be embedded in aircraft structures in locations where humidity and corrosion can accumulate but cannot be directly observed. A fiber-optic-FTIR experimental setup, including several samples of field corroded materials, has been assembled to spectrally detect Aluminum Hydroxide [Al(OH)3] which is one of the major components of aluminum corrosion. Absorption spectra of Al(OH)3, have been collected using an Attenuated Total Reflection (ATR) crystal as a reference spectral signature. The absorption spectra of samples from a simulated corrosion process and from the field corroded structures have been collected and compared with the reference Al(OH)3 spectra. Chalcogenide optical fibers are used for remote sensing purposes to detect corrosion. Two distinctive absorption peaks, attributable to aluminum hydroxide, are noticed from the simulated corrosion and from the field corroded structures.

8369-01, Session 1

Development of a SMART trap with integrated MEMS acoustic sensor for Asian ambrosia beetles

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Asian ambrosia beetles of the genus Xylosandrus are nonnative pests in the U.S. that attach both weakened and healthy trees and can potentially wipe out entire crops of nursery plants and forests. This pest threatens to reduce the productivity and profitability of commercial nursery and landscape businesses. For monitoring purposes, ethanol baited traps are commonly used to attract Asian ambrosia beetles, but these traps are nonspecific and attract many other insects as well. The goal of this research is to develop a SMART trap that attracts the Asian ambrosia beetle using olfactory and visual attractants. Among the various solvent combinations tested, a mixture of the two in a 50/50 ratio was most effective at selective attraction. LEDs (light emitting diode) emitting in green, blue, red and UV were used as visual attractants with green being the most effective attracting the beetles. In addition to the attractants, a MEMS (Micro-ElectroMechanical-Systems) piezoelectric acoustic sensor was integrated in the SMART trap to detect the distinctive acoustic signatures of the beetle from activities such as wing beats, chewing, and movement. The dimension and the geometry of the device were designed specifically to respond to the sound frequencies produced by target insects.

8369-02, Session 1

Preliminary results of radiometric measurements of clear air and clouds brightness (antenna) temperatures at 37GHz

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Radiophysical methods and means of remote sensing, such as radars, radiometers and combined radar-radiometers have wide application in meteorology and agriculture, for soil and atmospheric remote sensing. To achieve high accuracy and unambiguity in retrieval soil and snow moistures, soil temperature and snow melting time, precipitation quantity (clouds water content), snowfall and rainfall parameters, a synergy data of various independent and differing techniques and measurements at various frequencies and polarizations is necessary.

Hail and shower cause great and severe damage to agriculture and human properties. To reduce material damage in size it is necessary to have many stations of anti-hail protection equipped by hail clouds detector-classifiers. Usually, for hail detection a powerful Weather Doppler radar is used, operating at short centimeter or millimeter band of waves. These radars cost several hundred thousand USD, have serious disadvantages and cannot solve the problem totally. Therefore a reason is appeared to develop and to produce new kind of detector-identifiers, which will cost cheaper and have additional advantages.

Clouds brightness temperature is a function of many parameters, in which air and particles temperature, fraction type (water or ice) and particles size are the principal variables. The changes of clouds radio brightness temperatures, related with the changes of dielectric properties of particles and their temperatures, depend on frequencies and polarizations of observation. Therefore, by synergetic application of data of multi-frequency and multi-polarization microwave radiometric observations it is possible to detect and to recognize type of the clouds, its water content and the stage of transformation of water vapour and drops of water to hail (to ice). Radiometric observation may not miss the stage of transformation of water vapour and drops of water to hail, because water and ice dielectric constants are very differ and such formations' brightness temperatures will sufficiently vary one from the other. So, for precise and high probable detection and classification of hail clouds, for real time scale recording of hailing time, for upcoming hail storm's start time prediction, for retrieval of hail-stones' probable sizes, for assessment of expected quantity of hail precipitation it is necessary to develop multi-frequency and multi-polarization microwave radiometric system to carry out clear sky and clouds sustainable monitoring. Before that, it is necessary to specify appropriate frequencies and polarization for solution of hail clouds detection, classification and precipitation parameters and quantities assessment by multi-frequency and multi-polarization microwave radiometric system.

In this paper the results of polarization measurements of clear air and clouds brightness temperatures are presented. The results were been obtained during the measurements carried out in in Armenia from the measuring complex built under the framework of ISTC Projects A-872 and A-1524. The measurements were carried out at vertical and horizontal polarizations, under various angles of sensing by Ka-band combined scatterometric-radiometric system (ArtAr-37) developed and built by ECOSERV Remote Observation Centre Co.Ltd. under the framework of the above Projects. In the paper structural and operational features of the utilized system and the whole measuring complex will be considered and discussed as well.

The main technical characteristics of ArtAr-37 system's radiometer are presented below.

Central frequency - 37GHz

Horn antenna with a beamwidth - 70

Radiometer receivers bandwidth - ~1GHz

Radiometer Channel's sensitivity at 1s - ~0.3K

8369-03, Session 1

A multiplexing fiber optic microsensor system for monitoring oxygen concentration in plants during simulated climate change

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In biological systems, real-time measurement of oxygen levels and flux provides critical information for understanding the dynamics and physiology of this metabolite. Our research focus investigates the unknown effect of limited oxygen availability in plants due to climate change. Global atmospheric carbon dioxide levels and temperatures are predicted to increase rapidly in coming centuries. This may reduce oxygen availability in seed and reproductive structures, because higher temperature is expected to decrease oxygen solubility and increase metabolic demand for oxygen more than it increases oxygen molecular diffusivity. These changes are expected to adversely impact the reproductive processes and grain yield of seed-producing plants. For example, rising temperature decreases oxygen availability in soybean ovules, which in turn increases seed failure. To improve our understanding of the underlying physiological mechanism related to these adverse effects, we developed a multiplexing fiber optic microsensor system for monitoring oxygen concentration near or within different parts of plants, such as developing ovules, pollen grains and flowers. The fiber optic sensor tip diameters range in size from 0.1 mm to 800nm, and the sensors interface with a mechanical fiber multiplexer for multichannel monitoring. The detection system includes a frequency modulated LED for excitation (400nm), a B-390 filter to block longer wavelength emission, blue dichroic beamsplitter, and photomultiplier tube with O-56 filter and 10x objective. Sensor performance was enhanced by immobilizing titanium dioxide nanoparticles on the sensor surface.

Selection of optical components may be easily optimized to improve sensitivity if desired, and real time flux of other biologically significant molecules in plant systems, such as calcium, pH, and nitric oxide is also possible. This versatile, mobile microsensor platform allowed us to measure real time oxygen concentration in up to ten different soybean flowers, ovules, or seed-pods under various temperature and oxygen concentration conditions.

8369-04, Session 1

Biomass estimator for CIR-image with few additional spectral band images taken from light UAS

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VTT Technical Research Centre of Finland has developed a Fabry-Perot Interferometer based hyper spectral imager compatible with the light weight UAS platforms. The concept of the hyper spectral imager has been published in the SPIE Proc. 8174. Spectral camera images, CIR-images and point clouds extracted by automatic image matching will be used for biomass estimation to support precision farming. Images at a few properly selected spectral bands make it possible to achieve more accurate biomass estimation than what can be achieved with pure CIR-images. University of Jyväskylä has developed innovative way to produce biomass estimation for wheat and barley which can be generalized to many applications. MTT's test field at Vihti, Finland will be used as a training database for this estimator. Innovative estimator consists of several classification elements and it will produce median from all these classification results. This way more accurate result can be achieved and typical errors will be eliminated. Green, red and some NIR channel images will be added to the CIR data. These spectral bands are centered at 570, 660, 740, 800 and 855 nm. Fertilizer prediction maps will be done based to estimator results. Also variation of soils will be taken care of in estimation. Fields needs to be imaged before growing season to get the soil information for the estimation.

8369-05, Session 1

Development of band-selective 3CCD camera and application

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This study is focused on the development of band-selective 3CCD multispectral camera and its verification such that the detection of defects and the sorting for agricultural products. The idea of the developed camera is inspired by a conventional 3CCD camera. In comparison, the developed camera has the important feature that is the capacity of exchanging previously mounted optical filters for user-selected ones, that is performed through a distinctive mechanism. And its components are image sensors with VGA resolution, Image Signal Process Unit implemented by FPGA, FIFO memory for temporary saving of image data, and USB Interface Unit for communicating with PC. The user-selectivity of optical filter is enable to detect damaged tissues of some argicultural products caused by diseas, post-harvest process, and transferring injury; for detection of defects of Fuji apple required filters have the center wavelength of 780nm, 820nm, and 1000nm. and for sorting of intact and peeled garlice, it is required 820nm and 1000nm. On Fuji apple, the bruise can be detected from the subtraction of 820nm and 1000nm images, and bitter rot is done by the subtraction of 780nm and 1000nm images. The detection efficiency is 69% for the bruise and 95% for the bitter rot. The minimum diameter of bitter rot is about 2mm. On garlic, peeled cloves could be almost categorized against the intact through the segmentation of subtraction of 780nm and 1000nm band-passed images.

8369-06, Session 1

A nonrigid registration method for multispectral imaging of plants

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Recent advances in multispectral imaging have enhanced biological monitoring, e.g. virus infections of plants can be observed using NIR and chlorophyll fluorescence imaging before any virus symptoms can be seen using regular VIS images. In order to avoid expensive monitoring systems, many agricultural screening facilities build their own monitoring systems, often by gradually adding extra imaging modalities. Combining these different image modalities however is a non trivial task, since each imaging modality can have different focus settings, different lens distortions and might even been captured from a slightly different location or at a different angle.

This paper tackles these variations in image deformations, by proposing an non-rigid registration method. The registration problem is solved by optimizing the location of a set of virtual landmarks. Based on these virtual landmarks a non rigid deformation map is calculated using radial basis interpolation. The virtual landmarks are located in order to minimize a specific measure of similarity. This paper tests the influence of the following similarity measurements: cross-correlation, earth movers distance, mutual information and correlation ratio. Working on different image modalities, it might be interesting to work in specific feature spaces, instead of optimizing based on intensity. Therefore certain feature transforms such as edge maps, wavelet transforms, curvelet transforms etc. will be tested.

To experimentally test the different methods, 150 NIR and chlorophyll fluorescence images have been registered. Both NIR and fluorescence images have been manually segmented. The different registration methods are validated by comparing the registered segments using the Dice coefficient.

8369-07, Session 2

The development of line-scan image recognition algorithms for the detection of frass on mature tomatoes

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In this innovative research, the multispectral algorithm derived from hyperspectral line-scan fluorescence imaging under violet LED excitation was developed for the detection of frass contamination on mature tomatoes. The algorithm utilized the fluorescence intensities at five wavebands, 515 nm, 640 nm, 664 nm, 690 nm, and 724 nm, for computation of three simple ratio functions for effective detection of frass contamination. The contamination spots were created on the tomato surfaces using four concentrations of aqueous frass dilutions. The algorithms could detect more than 99% of the 0.2 g/ml and 0.1 g/ml frass contamination spots and successfully differentiated these spots from tomato surfaces, stem scars, and stems. The effective detection of frass showed that the simple multispectral fluorescence imaging algorithms based on violet LED excitation can be appropriate to detect frass contamination on fast-speed tomato post-harvest processing lines.

8369-08, Session 2

Hyperspectral imaging for detection of non-O157 Shiga-toxin producing Escherichia coli (STEC) serotypes on spread plates of mixed cultures

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Research Service (United States)

This study investigates the feasibility of visible and near-infrared (VNIR) hyperspectral imaging for rapid presumptive-positive screening of six representative non-O157 Shiga-toxin producing Escherichia coli (STEC) serotypes (O26, O111, O45, O121, O103, and O145) on spread plates of mixed cultures. Although the traditional culture method is still the "gold standard" for presumptive-positive pathogen screening, it is time-consuming, labor-intensive, not effective in testing large amount of food samples, and cannot completely prevent unwanted background microflora from growing together with target microorganisms on agar media. A previous study was performed to develop classification methods and prediction models to differentiate the six STEC serotypes but limited to data obtained from spot and/or spread plates of individual pure cultures. This study deals with problems caused by spectral and biological variability of the STEC serotypes growing together as mixed cultures. A new experimental procedure appropriate to a hyperspectral imaging study with mixed cultures is designed by finding optimal serial dilutions, incubation time, mixture formula, and validation methods of developed prediction models and classification methods so that the variability of data among experiments as well as within the same serotype can be minimized. The classification methods and prediction models developed from pure cultures are also validated with and refined for mixed culture data. Performance of new classification methods and prediction models directly developed from mixed cultures are compared with them obtained from pure cultures. If fully successful, this study will lead to a hyperspectral imaging technique for rapid screening of food samples contaminated by STEC pathogens.

8369-09, Session 2

Potential method of evaluating pork quality attributes during storage using hyperspectral imaging technique

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An optical method based on the hyperspectral imaging technique was exploited to evaluate the quality attributes of pork in the study. Fresh pork was purchased from local plants and stored at 4°C for 1-14 days. 3-4 samples were taken out of the refrigerator randomly for experiments each day during the storage time. The hyperspectral images of pork samples were collected in the spectral range of 400-1100 nm, and the reference tests for total viable counts (TVC) and total volatile basic-nitrogen (TVB-N) of samples were conducted in the meantime. The representative reflectance spectra and scattering profiles of the pork samples were extracted from the hyperspectral images respectively, and the scattering profiles were fitted by 4-parameter modified Gompertz function. The correlation between the optical reflecting information, scattering parameters of pork samples and the quality attributes of TVC, TVB-N during different storage time was studied respectively. Multi-linear regression (MLR) models were established to predict pork TVC and TVB-N respectively, and the models were validated independently. The study showed that hyperspectral imaging technique was useful in evaluating pork quality attributes during storage and this technique may be a valid alternative for comprehensively assessing meat quality and safety in the future.

8369-10, Session 2

Differentiation of toxigenic and atoxigenic fungi inoculated corn with hyperspectral imaging

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Corn contaminated with aflatoxin is toxic to domestic animals as well as humans and thus is of major concern to the food and feed industry. Aflatoxin levels in food and feed are regulated by the Food and Drug Administration (FDA) in the US, allowing 20 ppb (parts per billion) limits in food and feed for interstate commerce. Aflatoxin is produced by the fungus Aspergillus flavus when the fungus infects corn kernels. However, some of the A. flavi are toxin-producing and some of them are not. The objective of the current study was to assess, with the use of a hyperspectral sensor, the difference in fluorescence emission and reflectance between kernels treated with toxigenic and atoxigenic inoculums of A. flavus. The corn used was from a 2009 field experiment conducted in Baton Rouge, Louisiana. Corn ears were treated with aflatoxigenic AF13 and a non-aflatoxin producing strain AF38 at dough stage of growth and were harvested 8 weeks after treatment. Results are expected to enhance the potential of fluorescence hyperspectral imaging for detecting aflatoxin in corn.

8369-28, Poster Session

Hyperspectral imaging based techniques applied to wheat kernels characterization

S. Serranti, D. Cesare, G. Bonifazi, Univ. degli Studi di Roma La Sapienza (Italy)

Wheat is one of the most important staple foods in the world, being used as raw material for breads, cakes, cookies, pastries, crackers and pasta products. Its surface characteristics, as well as those of other cereal grains, can be investigated by hyperspectral imaging (HSI). Such an approach is based on the utilization of an integrated hardware and software architecture able to digitally capture and handle spectra as an image sequence, as they results along a pre-defined alignment on a surface sample properly energized. The study was addressed to investigate the possibility to apply HSI techniques for classification of different types of wheat kernels: vitreous, starchy and infected by fusarium. Reflectance spectra of selected wheat kernels of the three typologies have been acquired by a laboratory device equipped with two HSI systems working in two different spectral ranges: visible-near infrared (400-1000 nm) and near infrared field (1000-1700 nm). Classification based on principal component analysis of the spectral signatures has been applied. Results showed as the different wheat kernels can be correctly recognized.

8369-29, Poster Session

Dried fruits quality assessment by hyperspectral imaging

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Dried fruits products, such as hazelnuts and almonds, present different market values according to their quality. Such a quality is usually quantified in terms of freshness of the products, as well as presence of contaminants (pieces of shell, husk, small stones) and defects, mould and decays. The combination of these parameters, in terms of relative presence, represent a fundamental set of attributes conditioning dried fruits humans-senses-detectable attributes (visual appearance, organolectic properties, etc.) and their overall quality in terms of marketable products. Sorting-selection strategies exist but sometimes they fail when an higher degree of detection is required especially if addressed to discriminate between dried fruits of relatively small dimensions and when aiming to perform an "early detection" of pathogen agents responsible of future moulds and decays development. Surface characteristics of dried fruits can be investigated by hyperpectral imaging (HSI). In this paper, specific and "ad hoc" applications addressed to propose quality detection logics, adopting a hyperspectral imaging (HSI) approach, are described, compared and critically evaluated. Reflectance spectra of selected dried fruits of different quality and characterized by the presence of different contaminants and defects have been acquired by a laboratory device equipped with two HSI systems working in two different spectral ranges: visible-near infrared field (400-1000 nm) and near infrared field (1000-1700 nm). The spectra have been processed and results evaluated adopting both a simple and fast wavelength band ratio approach and a more sophisticated classification logic based on principal component (PCA) analysis.

8369-30, Poster Session

Bacterial detection using novel cell-based sensors

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In many environments bacteria grow in biofilms where they have increased resistance to commonly used antibiotics and disinfectants. Bacterial biofilm formation is coordinated by a cell-to-cell signaling phenomenon known as quorum sensing (QS) that is mediated by small secreted molecules. One QS molecule, autoinducer-2 (AI-2), is produced by numerous bacterial species and is therefore considered to be a universal cell-to-cell signaling molecule. Since biofilms are more resilient to disinfectant/antibiotic regimes an easy assay to identify the presence of biofilms could lead to better decisions about treatment procedures. In order to detect AI-2 which is associated with biofilm growth we engineered several E. coli cell-based sensor strains that detect presence of exogenous AI-2. The ability of these strains to act as AI-2 sensors was tested using purified AI-2 and AI-2 isolated from fuel/water mixtures. The ultimate goal is to use these cell-based sensors for detecting biofilms in diverse environment such as food, fuel storage containers/ pipelines and human infections.

8369-31, Poster Session

An investigation of FT-Raman spectroscopy for quantification of additives to milk powder

Y. Cheng, J. Qin, M. S. Kim, K. Chao, USDA Agricultural Research Service (United States)

Milk is a basic commodity important to human nutrition as a staple food and food ingredient. Instances of milk adulteration occurred in recent years, in which undisclosed additives were found in milk products, inappropriately added in order to affect flavor, color, and perceived nutritional value for commercial purposes-sometimes with significant food safety risks. This study established a rapid method using FT-Raman spectroscopy to quantify the presence of selected additives. Chemicals (melamine, urea, ammonium sulfate, and dicyandiamide) and protein (whey protein and pea protein) were mixed with dry milk powder at various concentrations, to investigate spectral detection and quantification. Relationships between ingredient concentration and the height and area of Raman spectral peaks were determined. Models were developed for quantitative analysis of these additives in milk.

8369-32, Poster Session

Integration of independent component analysis with near infrared spectroscopy for evaluation of rice freshness

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Determination of freshness is an important issue for rice quality. Current methods regarding the measurement of rice freshness are destructive, and the quality of rice cannot be recognized objectively and efficiently. Therefore, a rapid non-destructive inspection technique for determining rice freshness will serve as a useful tool. Near infrared (NIR) spectroscopy, a nondestructive inspection method based on specific absorptions within a given range of wavelengths corresponding to the constituents in the sample, has been widely applied for evaluation of internal quality of agricultural products. Since NIR spectra of a mixture may be approximated as the linear addition of individual spectra of the constituents in the mixture, such a mixture spectra thus can be regarded as ‘blind sources’ as the proportion of constituents in the samples remains unknown. A multiuse statistical approach, independent component analysis (ICA), which originally was used to implement ‘blind source separation’ in signal processing, is capable of disassembling the mixture signals of Gaussian distribution into non-Gaussian independent constituents with only a little loss of information. Because it does not require any information to be added to the source, ICA can give a complete explanation about the property of constituents in the mixture. Since applications of ICA for NIR qualitative analysis have been demonstrated by previous reports, ICA will be integrated with NIR spectral analysis to quantify the internal quality of rice in the present study, and quantitative models will be developed with ICA to evaluate rice freshness.

8369-33, Poster Session

classification of Korla fragrant pears using hyperspectral imaging

X. Rao, Zhejiang Univ. (China); C. Yang, USDA Agricultural Research Service (United States); Y. Ying, Zhejiang Univ. (China); M. S. Kim, K. Chao, USDA Agricultural Research Service (United States)

Korla fragrant pears are small oval pears characterized by light green skin, crisp texture, and a pleasant perfume for which they are named. Anatomically, the calyx of a fragrant pear may be either persistent or deciduous; the deciduous-calyx fruits are considered more desirable due to taste and texture attributes. Chinese packaging standards require that packed cases of fragrant pears contain 5% or less of the persistent-calyx type. Fluorescence hyperspectral imaging was investigated as a potential means for automated sorting of pears according to calyx type. Hyperspectral images spanning the 450 - 700 nm region were acquired using an EMCCD-based laboratory line-scan imaging system with 410 nm LED excitation. Analysis of the hyperspectral fluorescence images was performed to select wavebands useful for identifying persistent-calyx fruits and for identifying deciduous-calyx fruits. Based on the selected wavebands, an image-processing algorithm was developed that targets automated classification of Korla fragrant pears into the two categories for packaging purposes.

8369-34, Poster Session

Capsaicinoids content prediction model development for Korean red-pepper powder using a visible and near-infrared spectroscopy

J. Lim, K. Lee, C. Mo, S. Kang, National Academy of Agricultural Science (Korea, Republic of)

A non-destructive and real time pungency measuring system with visible and near-infrared spectroscopy has been recently developed to measure capsaicinoids content in red-pepper powder. Twenty red-pepper samples produced from 11 regions in Republic of Korea were used for the spectral assessment of capsaicinoids content without any chemical pretreatment. Partial Least Squares Regression (PLSR) models were developed to predict the capsaicinoids content from the spectra. The chemical

analysis of the total capsaicinoids (capsaicin and dihydrocapsaicin) was performed using a high performance liquid chromatographic (HPLC) method. In the wavelength range from 450 to 950 nm, the Standard Error of Prediction (SEP) was ±14.2 mg/100g from the developed prediction model of capsaicinoids content.

8369-35, Poster Session

Real-time multispectral fluorescence imaging techniques for on-line detection of contaminated poultry carcasses

B. Cho, Chungnam National Univ. (Korea, Republic of); M. S. Kim, USDA Agricultural Research Service (United States); D. Kim, I. Baek, C. Ahn, G. Kim, Chungnam National Univ. (Korea, Republic of)

Rapid and reliable inspection measurement methods are essential to ensure safety of food commodities in current mass production environment. Recent researchesof fluorescence imaging techniques have shown good potential for detection of contaminated food products. In this study, the feasibility of a real-time fluorescence imaging technique is explored for on-line detection of poultry feces on poultry carcasses. A multispectral line-scan imaging system integrated with a commercial poultry conveying system was constructed and its performance for detecting contaminated poultry was investigated at the processing line speed of over three to five poultry per second. It is indicated that the combination of two of two-band ratio fluorescence images could achieve detection of fecal spots on artificially contaminated poultry with above 99% detection accuracy. Results demonstrate that the real-time fluorescence imaging has good potential for the detection of contaminated poultry carcasses and could be an alternative to the current human inspection method in automated poultry processing plants.

8369-36, Poster Session

Flipping device for whole-surface online hyper-spectral imaging inspection of spinach

X. Tang, China Agricultural Univ. (China); C. Y. Mo, M. S. Kim, K. Chao, D. E. Chan, USDA Agricultural Research Service (United States); Y. Peng, China Agricultural Univ. (China)

On-line whole-surface imaging techniques are needed to implement high-speed inspection of leafy green vegetables for the presence of surface fecal contamination, which is a common source of pathogenic bacteria. One possible approach is to implement high-speed line-scan imaging inspection of leafy greens on a high speed conveyor belt. Effective inspection of vegetable greens such as baby spinach requires imaging of both adaxial and abaxial sides of individual leaves. This paper presents the development of a device customized to move and flip leafy greens between two parallel conveyors operating in opposite directions. Leaves travel on conveyor #1 past the imager, are turned and flipped to conveyor #2 which takes them past the imager again, thereby allowing imaging of both leaf sides. The kinematics and dynamics simulation for the spinach flipping device were carried out, and finally the experiments were conducted. This work provides the basis for development of online inspection technology that can be used by the commercial vegetable processing industry to reduce food safety risks.

8369-37, Poster Session

Multi-parameters quality prediction for fresh pork based on multi-spectral imaging and scattering characteristics

C. Li, Beijing Institute of Technology (China); Y. Peng, X. Tang, China Agricultural Univ. (China)

The rapid non-destructive inspection technique based optics is an important means for fresh pork quality detection. This paper studied on the possibility of using multi-parameters based on multi-spectral imaging technique and scattering characteristics to predict the quality of fresh pork. The quality parameters selected for prediction included total volatile basic nitrogen (TVB-N), color parameters (L *, a *, b *), pH value, and multi-spectral scattering images from fresh pork surface by a multispectral imaging system built by ourselves. The multi-spectral scattering images were acquired at the selected wavebands whose center wavelengths were 550, 560, 580, 600, 810 and 910nm respectively. In order to extract scattering characteristics from multi-spectral images at various wave lengths, the Lorentzian distribution function with four parameters (a: progressive values; b: peak; c: half-wave bandwidths; d: slope) was used to fit the scattering curve at the selected wavelengths.The results showed that the multispectral imaging technique combined with scattering characteristics is promised for predicting the quality of fresh pork meat.

8369-11, Session 3

Polymer based sensor array for phyotchemical detection

K. A. Weerakoon, B. A. Chin, N. Hiremath, Auburn Univ. (United States)

Plants emit phytochemicals as a defense mechanism when attacked by herbivores. Detecting these volatile organic compounds would enable detection of insect infestation at early stages. An electroactive polymer based chemiresistor sensor array was designed, fabricated and tested for phytochemical detection. This sensor array consisted of silicon platforms with interdigitated electrodes, made using standard micro fabrication procedures. The array consisted of 8 polymer/carbon composite film sensors, 3 polythiophene sensors and a polyaniline sensor. These sensors had different sensing mechanisms but the same actuator system, which optimized the selectivity of the sensor, while keeping the equipment simple. The electroactive polymers were drop casted or spin coated onto gold interdigitated electrodes patterned on silicon dioxide substrates. Carbon composites including polyvinylpyrrolidone, polyethyleneoxide, polyisoprene, polymethacrylate and polyethylene-co-vinylacetate (40% vinyl acetate) were selected for the sensor array based on the mass uptake of γ-terpinene. The sensor array was tested and found to be sensitive to a variety of volatile organic compounds including γ-terpinene, limonene, farnasene, α-pinene, p-cymene and cis-hexenyl acetate. Unique fingerprints for each of the analytes tested was obtained from the sensor array. The sensor array was able to distinguish between each of the analytes and hence can be used to detect insect infestation effectively. The sensor array was found to be stable under various environemtal conditions, including varying temperature conditions and humidity conditions. The sensors did not react with ambient gases. This made them excellent candidates as sensors for detecting insect infestation in agricultural fields that have constantly varying environmental conditions.

8369-12, Session 3

On-line detection of orange soluble solid content using visible and near infrared transmission measurements

X. Fu, Y. Ying, H. Xu, B. Qi, L. Xie, Zhejiang Univ. (China)

A prototype of on-line system developed by ourselves was used to non-destructively inspect orange quality and then classify. This system includes three main parts: machine vision part for fruit external quality detection, visible and near infrared (Vis-NIR) spectroscopy part for fruit internal quality detection, and weighing part for fruit weight detection. The fruit was scrolling on the roller in the machine vision part, while stop scrolling before entering the Vis-NIR spectroscopy part. Therefore, fruit

positions and directions were inconsistent for spectra acquisition. This paper was aimed to study the influence of fruit position and direction on spectra variation and model estimation performance using the on-line system. The system was configured to operate at typical grader speeds (270 mm/s or approximately three fruit per second) and detect the light transmitted through oranges in the wavelength range 600-950 nm. Multi linear regression models were developed for fruit with consistent directions and inconsistent directions, gave reasonable correlations $R2$ 0.8-0.9 and low cross validation errors (RMSECV 0.5-0.7%). Then these models were embedded in the software for on-line SSC prediction and classification of orange fruit. Two parameters were used for system and model performance evaluation, the RMSEP of the prediction set and the repeatability of SSC prediction (REP) of 10 times for certain samples. Good results were obtained with RMSEP 0.4-0.7% and REP$\leq$0.5%. The results showed that this on-line system can be used for SSC detection of thick-peel fruit like orange without considering the fruit directions.

8369-13, Session 3

Development of a single channel, three view imaging system with classification model for detect and damage assessment of freefalling cereal grains

I. Yang, S. R. Delwiche, USDA Agricultural Research Service (United States); Y. M. Lo, Univ. of Maryland, College Park (United States)

There are several different mechanisms to separate normal and damaged wheat kernels using physical properties such as density. However, some diseased kernels can't be easily detected. The expected developed system could be applied to raise the final quality of the sorted grains. Bichromatic sensor systems are often used in seed sorters. These systems work well when the condition of damage is evident throughout the seed, but the challenge arises when damage is localized. Our new study is aimed at the detection of damage occurring in regions of a wheat kernel. For example, damage from Fusarium or black tip that could be hidden from bichromatic systems may become evident through close-up high-speed imaging that permits the simultaneous capture of different views of a kernel in freefall. A two-mirror setting of the inspection system is being studied to determine whether sufficient image feature information is available to classify the normal and damaged kernels. The developed imaging system is capable of acquiring 640 x 480 10 bit images at 1/30,000 s exposure.A SIMCA approach is used on various morphological and textural image features. Aspects of hardware, optics, image processing and pattern recognition will be discussed.

8369-14, Session 3

3D imaging of tomato seeds using frequency domain optical coherence tomography

G. Yao, C. Fan, Univ. of Missouri-Columbia (United States)

A fast imaging system that can reveal internal sample structures is important for seeds research and quality controls. Optical coherence tomography (OCT) is a non-invasive optical imaging technique that can acquire high speed, high resolution depth-resolved images in scattering samples. It has found numerous applications in studying various biological tissues and other materials in vivo. A few groups have previously applied OCT to study seed morphology. However, 3D imaging of internal seed structure has not been reported before. In this study, we constructed a frequency domain OCT system to image tomato seeds. The system has a central wavelength of 845nm with a 47 nm bandwidth. The requirement for depth scan was eliminated by using a Fourier domain implementation. The B-scan imaging speed was limited by the spectroscopic imaging CCD at 52 kHz. The calibrated system has a 9 m depth resolution and a 30 m lateral resolution. Our results show that major seed structures can be clearly visualized in OCT images. Potential issues and future development are also discussed.

8369-15, Session 3

Measuring the optical properties of onion dry skin and flesh in the wavelength range from 400 to 1000 nm

W. Wang, C. Li, The Univ. of Georgia (United States)

Evaluating onions quality using optical techniques is challenging because the presence of outer dry skin and the layered structure of onion fleshy tissues. To better understand the light propagation in onions, optical properties of onion tissues were measured from 400 nm to 1000 nm. The dry skin and fleshy tissues of Vidalia sweet onion (c.v. Century), yellow onion (c.v. Vaquero), and white onion (c.v. White Cloud) were tested. Onion tissues were cut into 30 mm square pieces and sandwiched by Borofloat glass slides. The total diffuse reflectance and total transmittance spectra of the onion samples were measured by an integrating sphere system with a Vis-NIR spectrometer. The collimated transmittance spectra were directly measured by the spectrometer. The absorption coefficient (μa), reduced scattering coefficient (μs'), and anisotropy (g) of onion tissue samples were calculated using the inverse adding-doubling (IAD) method based on the measured spectra. The light penetration depth in onion tissues were estimated based on the calculated μa and μs'. Inverse Monte Carlo simulation (iMCS) was also used to recover the optical properties of onion tissues from the measured spectra. The accuracy of measurement was evaluated by comparing the onion optical properties obtained by using IAD method and iMCS. The results indicated that onion dry skins have much higher the absorption and reduced scattering coefficients than onion flesh tissues. Onion dry skin showed significant differences among the tested three varieties. The results of this study can be used to develop appropriate optical approaches for onion quality inspections.

8369-16, Session 4

Detecting multiple adulterants in dry milk using Raman chemical imaging

J. Qin, K. Chao, M. S. Kim, USDA Agricultural Research Service (United States)

Rapid and accurate authentication of food ingredients is important for food safety and quality evaluation. Raman chemical imaging has recently emerged as a novel technique for mapping constituents of interest in complex food matrices. This study aims to investigate the potential of macro-scale Raman chemical imaging for simultaneously detecting multiple adulterants in milk powder. Potential chemical adulterants (e.g., ammonium sulfate, calcium carbonate, dicyandiamide, melamine, sucrose, and urea) were mixed into dry milk at different concentrations. A benchtop point-scan Raman chemical imaging system was used to acquire hyperspectral images from the mixed powder samples. The system mainly consists of a 785 nm laser, a fiber optic probe, a dispersive Raman imaging spectrometer, a spectroscopic CCD camera, and a two-axis positioning table. It covers a Raman shift range of 100-2500 cm-1 with a spectral resolution of 3.7 cm-1. The Raman images were collected from an area of 25×25 mm2 with a spatial resolution of 0.25 mm from each mixed sample. Raman spectra of the pure chemicals were measured as references. An image classification method was developed based on self-modeling mixture analysis (SMA) to discriminate different adulterants in the milk powder. Pure component spectra of the individual chemicals were extracted from SMA, and they were identified by comparing to the reference spectra. Raman chemical images were created using the contributions corresponding to each component spectrum from SMA, and they can be used to visualize quantity and spatial distribution of the multiple adulterants in the dry milk.

8369-17, Session 4

Rapid detection of apple pesticide residue based on Raman spectroscopy

Y. Peng, Y. Sun, Y. Li, China Agricultural Univ. (China); K. Chao, USDA Agricultural Research Service (United States)

The feasibility study for potential use of Raman spectroscopy in the analysis of low concentration organic contaminants on apples' surface was conducted in this research. Chlorpyrifos was detected as a general organophosphorus pesticide for assessing apple safety. The characteristic peaks of fingerprints of pesticide on an aluminum substrate and apple fruit cuticle without pesticide residue were acquired first. Then a concentration range of chlorpyrifos (commercial products at 60%) solutions was made using deionized and distilled water. Single 100 μL droplets of the chlorpyrifos solutions were placed gently on apple fruit cuticles and left to dry before the test. Through comparative analysis of the Raman spectra data collected, it was observed that 341, 632 and 1237cm-1 peaks can be used to identify the chlopyrifos pesticide residue on apple's surface. Based on the relationship between the Raman intensity of the most prominent peak at around 632cm-1 and the pesticide concentrations, the limit of detection of ordinary Raman spectrum for chlorpyrifos is estimated to be 48ppm. The research demonstrated that Raman spectroscopic technique is a potential tool for real-time and non-destructive detection of apple pesticide residue.

8369-18, Session 4

In-situ identification of meat from different animal species by shifted excitation Raman difference spectroscopy

K. Sowoidnich, H. Kronfeldt, Technische Univ. Berlin (Germany)

The identification of food products and the detection of adulteration are of global interest for food safety and quality control. We present a non-invasive in-situ approach for the differentiation of meat from selected animal species using microsystem diode laser based shifted excitation Raman difference spectroscopy (SERDS) at 671 nm and 785 nm. In that way, the fingerprint Raman spectra can be used for identification without a disturbing fluorescence background masking Raman signals often occurring in the investigation of biological samples.

Two miniaturized SERDS measurement heads including the diode laser and all optical elements are fiber-optically coupled to compact laboratory spectrometers. To realize two slightly shifted excitation wavelengths necessary for SERDS the 671 nm laser (spectral shift: 0.7 nm, optical power: 50 mW) comprises two separate laser cavities each with a volume Bragg grating for frequency selection whereas the 785 nm light source (spectral shift: 0.5 nm, optical power: 110 mW) is a distributed feedback laser.

For our investigations we chose the most consumed meat types in the US and Europe, i.e. chicken and turkey as white meat as well as pork and beef as red meat species. The applied optical powers were sufficient to detect meat Raman spectra with integration times of 10 seconds pointing out the ability for a rapid discrimination of meat samples. Principal components analysis was applied to the SERDS spectra to reveal spectral differences between the animals suitable for their identification. The results will be discussed with respect to specific characteristics of the analyzed meat species.

8369-19, Session 4

Rapid analysis of foodborne pathogens by surface-enhanced Raman spectroscopy

S. R. Farquharson, Real-Time Analyzers, Inc. (United States)

Foodborne diseases resulting from Campylobacter, Escherichia, Listeria, Salmonella, Shigella and Vibrio species affect as many as 76 million persons in the United States each year, resulting in 325,000 hospitalizations and 5,000 deaths. The challenge to preventing distribution and consumption of contaminated foods lies in the fact that just a few bacterial cells can rapidly multiply to millions, reaching infectious doses within a few days. Unfortunately, current methods used to detect these few cells rely on lengthy growth enrichment steps that take a similar amount of time (1 to 4 days). Consequently, there is a critical need for an analyzer that can rapidly extract and detect foodborne pathogens in 1-2 hours (not days), at 100 colony forming units per gram of food, and with a specificity that differentiates from indigenous microflora, so that false alarms are eliminated. In an effort to meet this need, we have been developing a sample system that extracts such pathogens from food, selectively binds these pathogens, and produces surface-enhanced Raman spectra (SERS). Here we present preliminary SERS measurements of E. coli, Listeria and Salmonella.

8369-20, Session 5

Identification of Shiga toxin-producing Escherichia coli (STEC) serotypes with hyperspectral microscope imagery

B. Park, W. R. Windham, USDA Agricultural Research Service (United States); H. Kwon, P. Gurram, U.S. Army Research Lab. (United States); S. R. Ladely, S. C. Yoon, K. C. Lawrence, N. Narang, W. C. Cray, USDA Agricultural Research Service (United States)

Shiga toxin-producing Escherichia coli (STEC) is a type of enterohemorrhagic E. coli (EHEC) bacteria that can cause illness ranging from mild intestinal disease to severe kidney complications. Other types of enterohemorrhagic E. coli include the relatively important serotype E. coli O157:H7, and more than 100 other non-O157 strains such as O26, O45, O103, O111, O121 and O145. Those serotypes are recognized as serious outbreak to cause human illness due to their toxicity. A conventional microbiological method for cell counting is still being used as a gold standard for foodborne pathogenic bacteria detection. This method, however, is laborious and needs long time for the results. Therefore, the accurate and rapid methods for foodborne pathogen detection are needed for better performance. Since optical detection method is promising for real-time, in-situ foodborne pathogen detection, hyperspectral microscopic imaging methods will be an effective tool for identifying pathogenic bacteria because of its capability to differentiate both spatial and spectral characteristics of each bacterial cell from micro colony samples. The objective of this research is to develop a hyperspectral microscopic imaging method to evaluate spectral characteristics of foodborne pathogen specifically STEC. The acousto-optic tunable filters (AOTF)-based hyperspectral microscope imaging (HMI) system with EMCCD camera and dark-field illumination was used for image acquisition from six different serotypes described above. The spectral images at the wavelength ranges of 450 to 800 nm with 4-nm interval with three different gains (27, 54 and 103) and integration times (50, 100, 250 and 500 ms) were analyzed for quality image acquisition. In this paper, the AOTF-based hyperspectral microscope imaging method to identify STEC serotypes with classification algorithms including support vector machine (SVM) and sparse kernel-based ensemble learning (SKEL) will be presented.

8369-21, Session 5

In-situ detection of Salmonella Typhimurium on tomatoes using magnetoelastic biosensors and a flat magnetic coil

Y. Chai, L. C. Mathison, S. Li, S. Horikawa, M. Park, V. A. Petrenko, B. A. Chin, Auburn Univ. (United States)

Foodborne illness continues to be a threat to every man, woman and child. A portable, held-held sensor for the detection of pathogenic bacteria and spores on fresh produce would greatly reduce the incidence of foodborne illness. The magnetoelastic (ME) biosensor is wireless device that may enable the detection of very small amounts of pathogenic bacteria on fresh produce. The ME biosensor is constructed of a small rectangular strip of magnetoelastic material that is coated with a biomolecular recognition element (phage, antibodies or proteins, etc.) that is specific to the target pathogen. Upon coming in contact with the target pathogen the biomolecular recognition element binds the target pathogen to the surface of the ME biosensor. The additional mass of the bound bacteria causes a change in the resonance frequency of the ME biosensor. This resonance frequency is measured wirelessly and nearly instantaneously using a time varying magnetic field. New research, reported in this paper shows that these ME biosensors may be placed directly on the surface of fresh produce and a handheld flat coil used to measure the biosensors. In previous research, ME biosensors were placed on fresh produce spiked with a known concentration of pathogenic bacteria. The ME biosensors bound with the pathogenic bacteria and the sensors were retrieved and measured using a field portable measurement system. The previous system has now been improved by the construction of a flat pickup coil that can be used to measure resonance frequencies of ME biosensors while they reside on the fresh produce. Optimization of the coil design was performed to improve the signal amplitude. Meanwhile, a strong and uniform static magnetic field was also added to magnify the signal. E2 phage-based ME biosensors were used to detect Salmonella Typhimurium on tomato surfaces. The flat magnetic coil was brought close to the sensors to capture changes in the sensor's resonant frequency due to the mass change. With control sensors compensating for background noise, the ME biosensors were used to detect Salmonella Typhimurium on tomatoes in real-time.

8369-22, Session 5

Rapid, enhanced detection of Salmonella Typhimurium on fresh spinach leaves using micron-scale, phage-coated magnetoelastic biosensors

S. Horikawa, K. Vaglenov, D. M. Gerken, Y. Chai, M. Park, S. Li, V. A. Petrenko, B. A. Chin, Auburn Univ. (United States)

We have previously demonstrated the rapid detection of Salmonella Typhimurium (< 30 min) on various fresh produce surfaces using millimeter-scale, phage-coated magnetoelastic (ME) biosensors. These biosensors were constructed of a rectangular magnetostrictive strip (1 or 2 mm in length) coated with a filamentous phage that is engineered to specifically bind with S. Typhimurium. These phage-coated biosensors were, without any sample preparation, directly placed on wet produce surfaces pre-inoculated with various concentrations of S. Typhimurium. Upon contact, the affinity-selected phage binds the bacterium to the sensor, thereby increasing the total mass of the sensor. This change in mass causes a corresponding decrease in the sensor's resonant frequency, which can be monitored in real-time by a wireless means. The results from the previous investigations have shown that selective binding of S. Typhimurium on the phage-coated biosensors could occur in comparison with control sensors (without phage). However, the limits of detection (LOD) were found to be largely dependent on the surface morphology of the fresh produce of interest as well as the size of the sensors due to the non-uniform surface distribution of the bacterium. Hence, this paper presents an investigation into the use of micron-scale ME biosensors (175 um in length) for the enhanced detection of S. Typhimurium on fresh spinach leaves that in general have a higher surface roughness. The results showed that the LOD was improved which is attributed to the improved contact between the sensors and the bacterium as well as the higher mass sensitivity of the micro-scale biosensors.

8369-23, Session 5

Identification and characterization of Salmonella serotypes using their DNA/RNA fingerprints analysis by Fourier transform infrared (FT-IR) spectroscopy

J. Sundaram, B. Park, A. Hinton, S. C. Yoon, K. C. Lawrence, USDA Agricultural Research Service (United States)

Rapid identification of foodborne bacteria and its serotypes have more demand in food safety practices. Bacteria identification and classification are carried out using conventional methods based on serological test and molecular methods. In these methods DNA and RNA finger prints are used to identify the serotypes. Conventional methods take long time to identify single serotype of bacteria. Fourier Transform infrared spectroscopy (FT-IR) has been in use of computational analysis and it was introduced into in-situ analysis of bacteria cell complex to detect and identify them. Since then there is growing demand for FT-IR spectroscopy analysis of foodborne pathogens. It has advantage of technical advancement, simplicity of sample preparation and analysis speed. DNA and RNA are the backbone structures that contain more variations in structural features of each bacterial serotype compared to other structural components. Therefore in this study DNA and RNA structural components were extracted from different serotypes of Salmonella bacteria to identify their serotypes using FT-IR spectroscopy. Extracted material was loaded individually on the ZnSe Attenuated Total Reflection (ATR) crystal surface and scanned, and then spectra were recorded from 4000 cm-1 to 650 cm-1 wave number. Analysis of spectral signatures of Salmonella serotypes were conducted using Principle Component Analysis (PCA). PCA models were developed to differentiate them. Classification among each serotype was confirmed by calculating Mahalanobis distance between each type on their PCA score plot. Structural characteristics differences among the serotypes have been studied.

8369-24, Session 6

Detection of Salmonella using autonomous magnetoelastic biosensor system

S. Li, Y. Chai, M. Park, S. Horikawa, B. A. Chin, Auburn Univ. (United States)

In order to quickly respond to an outbreak of foodborne disease, detection of foodborne bacteria requires rapid response time and high sensitivity. However, according to a study in bio-reaction dynamics, the chance of interaction between bacteria and biosensor are very low when the bacteria is in low concentration within an analyte, resulting in very long response times and limited sensitivity. This paper presents an investigation of the detection of foodborne bacteria using autonomous magnetoelastic (ME) biosensors that have the capability to seek out and detect bacteria in a liquid environment. The autonomous ME biosensor is comprised of a freestanding ME resonator (transducer platform) that is coated with a biorecognition layer that specifically captures the target pathogen. The ME resonator oscillates under alternating magnetic fields and its resonant frequency is monitored wirelessly through magnetic signals. Due to their magnetic nature, ME biosensors can be driven to move through an analyte using a magnetic field. Upon contact with the target pathogen, the biorecognition layer on the sensor will bind with the target cell. This binding causes a change in the resonator mass, which results in a change in the sensor's resonant frequency and the instantaneous detection of the target pathogen. In this study, E2 phage (specifically binding with Salmonella) coated ME biosensors were fabricated. Salmonella analytes with different concentrations were detected with both stationary and autonomously moving ME biosensors. These results show that the detection of bacteria using autonomously moving biosensors improves the response time and the detection limit. ~

8369-25, Session 6

Impedance biosensor based on double interdigitated electrode arrays for detection of E.coli O157:H7 in food products

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Almasri, Univ. of Missouri-Columbia (United States)

We have designed, fabricated and tested impedance biosensor for detection of viable Escherichia coli O157:H7 in food products. The device consists of two set of interdigitated microelectrode array (IDA) fabricated using thin layer of sputtered gold embedded in SU-8 microchanels with different dimensions. The first use negative dielectrophoresis to focus and concentrate the E-Coli into another channel with a diameter 3 times smaller and located in the center where the second set of IDE that are used to detect E-Coli are located. The contaminated food samples were tested by infusing over the IDA's, through the microchannel. Non-cellular bodies exit the system through the outer two outlets and the bacteria enriched sample continues to the detection IDA. The active surface area of the detection array was modified using goat anti-E.coli polyclonal IgG antibody. Antibody-antigen binding on the electrodes, results in impedance change. Four serial concentrations of E.coli contaminated food samples (3x102 CFUml-1 to 3x105 CFUml-1) were tested in grape, turkey meat and spinach. The impedance responses were recorded for frequencies ranging between 100Hz -1MHz.The biosensor successfully detected the E.coli samples, with the lower detection limit of 3x103 CFUml-1 (up to 3cells/µl). In addition, we have fabricated and tested an IDA array impedance biosensor without microchannel. The testing results indicate that the biosensor with a microchannel is two order of magnitude times better. The proposed biosensor provides qualitative and quantitative detection, and potentially could be used for detection of other type of bacteria by immobilizing the specific antibody.

8369-26, Session 6

Comparison of phage-based magnetoelastic biosensors with TaqMan-based quantitative real-time PCR for the detection of Salmonella Typhimurium directly grown on tomato surfaces

M. Park, S. Li, S. Horikawa, Y. Chai, H. C. Wikle III, B. A. Chin, Auburn Univ. (United States)

A phage-based magnetoelastic (ME) biosensor method was compared with a TaqMan-based quantitative real-time PCR (qRT-PCR) method for the detection of Salmonella Typhimurium on tomato surfaces. This ME biosensor method utilizes magnetoelastic resonators coated with E2 filamentous phage to bind with and measure the concentration of S. Typhimurium. In this study, standard curves, correlations, and limits of detection (LOD) for the ME biosensor and TaqMan-based quantitative real-time PCR (qRT-PCR) methods were determined by inoculating tomato surfaces with S. Typhimurium suspensions in concentrations ranging from 1 to 8 log CFU/tomato. The LOD for the ME biosensor method and qRT-PCR were 3 and 2 log CFU/tomato, respectively. In a direct comparison of the detection methods, S. Typhimurium suspensions (3 log CFU/tomato) were inoculated on 65 tomato surfaces, then incubated at 37 °C and 100% RH for 24 h. After 24 h, S. Typhimurium was positively detected by both methods and the quantified concentrations were nearly the same, (6.31 ± 1.43) and (6.34 ± 0.17) log CFU/tomato respectively for the ME biosensor method and the qRT-PCR method, which were significantly greater than the concentration determined by the BGS-plate count method (5.33 ± 0.21). Scanning electron microscopy (SEM) was used to confirm the growth of S. Typhimurium on the tomato surfaces and the binding of S. Typhimurium on the measurement sensors. This study demonstrated that the ME biosensor method was robust and competitive to qRT-PCR for S. Typhimurium detection on fresh produce.

8369-27, Session 6

Optimization of blocking of nonspecific binding on phage-based magnetoelastic biosensors

W. Shen, M. Park, S. Li, S. Horikawa, Y. Chai, L. C. Mathison, V. A. Petrenko, B. A. Chin, Auburn Univ. (United States)

Food safety of fresh agricultural products has recently become a very important issue for the public and for producers. During the past few years there have been a number of outbreaks of foodborne pathogens on fresh produce, resulting in sickness, death, and significant cost to the industry. A sensor is needed to quickly detect these pathogens on produce with a high sensitivity and selectivity. We have previously demonstrated the ability of sensors based on magnetoelastic platforms to detect Salmonella typhimurium. The platform is coated with E2 filamentous phage designed to bind specifically with S. typhimurium. Detection is realized by monitoring the resonant frequency change as bacteria are bound to the phage, causing a mass change of the sensor. This paper presents research for optimizing the blocking conditions to further improve the sensitivity of these sensors. Studies were made on hundreds of sensors used for measurement and control for determining an optimum condition of the blocking agent for highest ratio of binding on the measurement sensors to the non-specific binding on the control sensors. The sensors were subjected to various concentrations of BSA, bovine fat free milk and casein milk protein. Measurements were compared with SEM pictures to show how binding of Salmonella to the sensor is affected by the type and the concentration of the blocking agents. Results show that BSA is the best agent for sensitivity and that a concentration of 1.0 mg/ml gives the best ratio of binding to non-specific binding for S. typhimurium.

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8370-01, Session 1

Photonic crystal fibers and applications in sensing

B. J. Mangan, OFS Fitel (United States)

Photonic crystal fibers are pure silica optical fibers with an array of air holes that run along the length. The development of these fibers, in both solid and hollow core varieties, has been significant over the past 15 years and they are increasingly finding new applications in a variety of sensing areas. This talk will present some of the background of photonic crystal fibers, the current understanding of the optical properties, performance and limitations of the fibers and how they are being used in the world of sensors.

8370-02, Session 2

Long-period gratings in photonic crystal fibers operating near the phase-matching turning point for evanescent chemical and biochemical sensing

J. Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic)

Fiber-optic long-period grating (LPG) operating near the dispersion turning point in its phase matching curve (PMC), referred to as a Turn Around Point (TAP) LPG, is known to be extremely sensitive to external parameters. Moreover, in a TAP LPG the phase matching condition can be almost satisfied over large spectral range, yielding a broadband LPG operation. TAP LPGs have been investigated, namely for use as broadband mode convertors and biosensors. So far TAP LPGs have been realized in specially designed or post-processed conventional fibers, not yet in PCFs, which allow a great degree of freedom in engineering the fiber's dispersion properties through the control of the PCF structural parameters. We have developed the design optimization technique for TAP PCF LPGs employing the finite element method for PCF modal analysis in a combination with the Nelder-Mead simplex method for minimizing the objective function based on target-specific PCF properties. Using this tool we have designed TAP PCF LPGs for specified wavelength ranges and refractive indices of medium in the air holes. Possible TAP PCF-LPG operational regimes - dual-resonance, broadband mode conversion and transmitted intensity-based operation - will be demonstrated numerically. Potential and limitations of TAP PCF-LPGs for evanescent chemical and biochemical sensing will be assessed.

8370-03, Session 2

Modal reduction in 6-rod bundled single-crystal sapphire photonic crystal fibers

N. T. Pfeiffenberger, G. Pickrell, Virginia Polytechnic Institute and State Univ. (United States)

This paper presents the results of the finite element modeling of a unique 6-rod bundled sapphire photonic crystal fiber. The structure is composed of of five rods of single crystal sapphire fiber 70µm in diameter symmetrically arranged around a solid single crystal sapphire core region, which is 50µm in diameter. The modeling work focuses on the optimization and modal analysis of this photonic crystal fiber using Comsol Multiphysics 4.2. In sensor design and realization, reduction of the modal volume of the fiber can offer significant advantages, and as such, this research work is focused on computational determination of the structures which may minimize the number of modes of the sapphire photonic crystal fiber. The fiber design being analyzed in this paper may be especially important for sensors operating in harsh high temperature environments.

8370-04, Session 2

Computational design of a strain fiber optic sensor

A. Yarce Botero, Univ. EAFIT (Colombia)

I will expose a Computational analysis method for a design of a strain fiber optic sensor. I will use three different software programs. The first program will be MAPLE for the develop of the numerical and symbolic computations, the second program will be ANSYS for the structural analysis and the third one will be OPTIFIBER for the analysis of electromagnetic modes in the optic fiber. The design strategy is to translate the deformations of structures in changes in the refractive index of the optic fiber and the subsequent modification of the electromagnetic modes of the fiber. This strategy will be presented in detail from a computational mathematic point of view. Is hoped that this design method proposed be useful for engineers working with optic fiber

8370-05, Session 2

Modeling of low-finesse, extrinsic fiber optic Fabry-Perot whitelight interferometers

C. Ma, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

This article reviews several key approaches in modeling fiber optic low-finesse extrinsic Fabry-Perot Interferometers (EFPI), which aim to address signal processing problems in EFPI sensor demodulation algorithms based on white light interferometry. The main goal of the models is to seek physical interpretations to correlate the sensor spectrum with the interferometer geometry (most importantly, the optical path difference (OPD) of the cavity). Because the signal demodulation quality and reliability hinge heavily on the understanding of such relationships, the models shed light on an avenue toward optimal system performance.

8370-06, Session 2

Computational design of a fiber optic temperature sensor

D. Campo, Univ. EAFIT (Colombia)

I will present a computational method for the analysis and design of a temperature sensor of optical fiber.I will combine symbolic and numerical computations using the following software:Maple, For symbolic computation.Ansys: For the numerical-graph computation of temperature profiles.Opticfiber: For the numerical computation graph of the electromagnetic modes in the fiber optics.

The design strategy is to convert the patterns of temperature changes in the refractive index of the fiber and the detection of changes in the electro-optical normal modes in the fiber. The proposed method has many advantages for the design of optical fiber sensors nowadays, for tempeture measurements as well for other physical variables.

8370-07, Session 3

Temperature and pressure sensors based on chiral fibers

V. I. Kopp, J. Park, M. S. Wlodawski, D. Neugroschl, J. Singer, A. Z. Genack, Chiral Photonics, Inc. (United States)

We have fabricated both pressure and temperature sensors based on chiral fiber gratings that can operate in harsh environments over wider measurement ranges than conventional fiber Bragg gratings (FBGs). Chiral fiber sensors are made by twisting one or more standard or custom optical fibers with a noncircular or non-concentric core as they pass though a miniature oven. Because the resulting structures are as stable as the glass material, they can operate within harsh environments. Excellent temperature stability up to 900°C is found in pure silica chiral fiber sensors. In conjunction with a standard FBG interrogator, we developed a correlation algorithm to accurately measure the shift in the transmission spectrum as the local environment of the sensor changes. We developed a calibration procedure, which allows the chiral temperature sensor to operate at temperatures from 200°C to as high as 900°C with a maximum difference of +/- 2°C as compared to a calibrated thermocouple. We have fabricated a pressure sensor operating from 1 atmosphere (14.7 psi) up to 12 Kpsi with a resolution of 1 psi that can operate at temperatures as high as 700°C.

8370-08, Session 3

Field testing the Raman gas composition sensor for gas turbine operation

M. P. Buric, B. T. Chorpening, J. C. Mullen, J. A. Ranalli, S. D. Woodruff, National Energy Technology Lab. (United States)

A gas composition sensor based on Raman spectroscopy using reflective metal lined capillary waveguides is tested under field conditions for feed-forward applications in gas turbine control. The capillary waveguide enables effective use of low powered lasers and rapid composition determination, for computation of required parameters to pre-adjust burner control based on incoming fuel. Tests on high pressure fuel streams show sub-second time response and better than one percent accuracy on natural gas fuel mixtures. Fuel composition and Wobbe constant values are provided at one second intervals or faster. The sensor, designed and constructed at NETL, is packaged for Class 1, Division 2 operations typical of gas turbine environments, and samples gas at up to 800 psig. Simultaneous determination of the hydrocarbons methane, ethane, and propane plus CO, CO2, H2O, H2, N2, and O2 are realized. The capillary waveguide permits use of miniature spectrometers and laser power of less than 100 mW. The capillary dimensions of 1 m length and 300 µm ID also enable a full sample exchange in 0.4 s or less at 5 psig pressure differential, which allows a fast response to changes in sample composition. Sensor operation under field operation conditions will be reported.

8370-09, Session 3

Advanced fiber optic fluorescence turn-on molecular sensor for highly selective detection of copper in water

Y. Chiniforooshan, J. Ma, W. J. Bock, Univ. du Québec en Outaouais (Canada); W. Hao, Z. Y. Wang, Carleton Univ. (Canada)

In this article a novel advanced fiber-optic fluorescent sensor is demonstrated. The sensor is based on collection of the fluorescence from the side wall of the multimode optical fiber which is partly uncladed and covered by the sample under the test. The most part of the fluorescent intensity is carried by higher order modes which are inaccessible in traditional evanescent-wave fluorescence fiber sensors. In the proposed structure higher order modes including tunneling modes as well as some part of refracting power are collected and transformed into the lower order lossless modes by side wall and by end face mode mixer. In addition to the higher level of Fluorescence collection, the architecture allows us to multiplex several different channels along one fiber, since we use only a small segment of the sidewall for each channel.

A highly efficient fluorescence turn-on molecular probe is applied to this advanced fiber-optic structure, for sensitive and selective detection of Cu in aqueous solution. The fluorescence turn-on molecular probe is a mixture of David's polymer (0.3 mMol/L) and PpQDM solutions (0.2mg/L). David's polymer solution is used as an indicator which is generating the fluorescence centered at the wavelength of 705nm and then with a proper amount of the PpQDM the fluorescence can be quenched up to 80% of its maximum intensity. In addition, PpQDM is a highly selective acceptor of Cu molecules. Cu reacts with PpQDM and the quenched fluorescence is released again. This turn-on effect is used for sensing of Cu with a low detection limit of 0.02689g/mL. We believe it is a first highly efficient fiber-optic sensor for metal detection in water.

8370-10, Session 4

Multimode interference as a tool for fiber sensing

S. F. Oliveira Silva, O. Frazão, L. A. Ferreira, F. M. Araújo, INESC Porto (Portugal); J. L. Santos, Univ. do Porto (Portugal)

No abstract available.

8370-11, Session 4

Novel photonic crystal fiber optofluidic sensing platform enabled through layer-by-layer assembly of pH-responsive polyelectrolytes

F. Tian, Stevens Institute of Technology (United States); J. Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); S. A. Sukhishvili, H. H. Du, Stevens Institute of Technology (United States)

A vast number of polyelectrolytes exist that are responsive to a multitude of environmental stimuli such as pH, ionic strength, and temperature. We have exploited such characteristics through layer-by-layer (LbL) self-assembly of pH-sensitive poly(vinyl pyrrolidone) (PVPON) and poly(methacrylic acid) (PMAA) bilayers in index-guiding photonic crystal fiber (PCF) with CO2 laser-inscribed long-period gratings (LPG). LPG structures formed in conventional single mode optical fiber are used for parallel studies. The highly sensitive nature of our PCF-LPG as an index transduction platform allows in-situ monitoring of the deposition process of the LbL itself, revealing a red shift of 5.5 nm per PVPON/PMAA bilayer formed. We show that the resonance wavelength of PCF-LPG with PVPON/PMAA bilayers exhibits a rapid and significant shift in response to the change in the solution pH. The experimental results have been correlated to numerical simulations using a full-vector mode solver based on the Finite Element Method (FEM) in terms of the wavelength dependence of the effective indices and electric field distributions of the modes in the LbL-functionalized PCF-LPG.

8370-12, Session 4

Competitive Raman gain and signal attenuation in PCF: an integrated theoretical and experimental study using SERS nanotags

P. Pinkhasova, Stevens Institute of Technology (United States); J. Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); S. A. Sukhishvili, H. H. Du, Stevens Institute of

Technology (United States)

The competitive Raman gain and scattering/absorption-induced signal attenuation over the length of a waveguide decorated with SERS-active Ag or Au nanoparticles depends critically on the particle size and coverage density. We have carried out a combined theoretical and experimental investigation of this complex interplay to ascertain optimal nanoparticle parameters for SERS-active photonic crystal fiber sensors. In particular, discrete dipole approximation (DDA) and finite difference time domain (FDTD) simulation methods have been used to evaluate the interaction of the evanescent field of the guided core with immobilized nanoparticles (diameter: 20-100 nm, coverage: 0.1-5 particles/μm2). Favorable nanoparticle parameters have been experimentally assessed using well-behaved, individually SERS-active Au shell-Ag core nanotags that are immobilized on the cladding air channels of a suspended core PCF. The theoretical calculations and experimental findings will be compared and contrasted, using the optical path length (i.e., fiber length) as a means of further increasing the detection sensitivity of the SERS-active PCF.

8370-13, Session 4

Long-period gratings in photonic crystal fiber for sensitive gas phase measurements

F. Tian, Z. He, Stevens Institute of Technology (United States); J. Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); H. H. Du, Stevens Institute of Technology (United States)

We report an investigation of long-period gratings (LPG) in photonic crystal fiber (PCF) as a robust index transduction platform for gas sensing and detection. LPG of varying grating periodicities have been inscribed in index-guiding PCF using CO2 laser irradiation to induce the core mode to cladding mode coupling at some resonance wavelengths. The resultant PCF-LPG schemes have been used to measure the shift in the resonance wavelength upon filling the PCF air cladding with helium, argon and acetylene. We reveal that the longer the resonance wavelength, the greater its shift, thus the higher the sensitivity to refractive index changes in the air cladding. We show that a sensitivity as high as 1250 nm per refractive index unit can be achieved. Theoretical simulations using the finite difference frequency domain (FDFD) method are used as a guide to interpret our experimental results.

8370-14, Session 5

Advanced Fiber Optical Sensor and Instrumentation for Power Generation Industrial Monitoring and Diagnostics

H. Xia, General Electric Global Research (United States)

Temperature measurement in an extremely harsh environment, such as in a coal gasifier and gas turbine, presents significant challenges to any conventional temperature sensing technology, including thermocouple, IR camera, pyrometer, and blackbody radiation measuring methods. The commonly used fiber Bragg grating (FBG)-based temperature sensors have many advantages, making them very successful in structural health monitoring application. However, conventional FBG sensors have poor thermal stability and high-temperature survivability when environmental temperature is beyond 300C. This talk presents a band-gap engineering method to turn conventional amorphous fiber material into highly thermal stabilized tetrahedral structure, and the inscribed FBG sensor have shown the same fundamental characteristics as conventional FBG sensor but the tetrahedral dominated fiber material enables such FBG sensors more tolerable to extremely temperature without losing structure integrity. The prototyped tetrahedral FBG sensors were packaged and integrated with a sootblower for coal gasification RSC vessel radial and axial distributed temperature or thermal profile measurements. The laboratory and field validations at Tampa Electric Company (TECO) have demonstrated these tetrahedral FBG sensors and package can provide reliable temperature measurement under 1200C and 800 psig harsh conditions. In addition, the applications with these tetrahedral FBG sensors for gas turbine exhaust and steam generation pipe thermal trend and degradation will be also discussed.

8370-15, Session 5

Distributed temperature sensing for an embedded turbine measurement application

Y. Wang, J. Gong, D. Y. Wang, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

Temperature measurement of aircraft-turbine-engine requires the sensor to have such features as: small size, high temperature endurance and distributed measurement. In this paper, we report the distributed temperature measurement at 650°C based on 17 time division multiplexed (TDM) fiber Bragg gratings. This sensor link was attached on a coupon in a spiral shape from 2” inner diameter to 4” outer diameter. With this spiral shape layout, the thermal field of the coupon can be reconstructed. First, a TDM interrogation system was used to realize the simultaneous measurement of 17 FBGs. This system can provide 5cm spatial resolution and less than 1 minute response time. The potential multiplexing capability of this scheme is more than 1000 without the limitation of operation distance. Secondly, the high temperature (650°C) performance of FBG was investigated. Proper annealing was applied to stabilize the performance of the FBGs. Thirdly, the coating of standard single mode fiber will be gasified at 650°C and the fiber cannot survive in a spiral shape. Thus several materials and methods investigated from two major aspects: high temperature endurance and protection ability for bent-fiber. The demonstrated minimum diameter is 2” and the tested temperature is 650°C. With proper sensor package, the sensor link was attached on the coupon and thermal cycling test was conducted for 72 hours. Experiment results demonstrated that the thermal field of the coupon can be reconstructed by the multiplexed FBG sensor link.

8370-16, Session 5

Design validation of an air cooled turbo generator by using fibre optic sensors in a shop test

T. Bosselmann, M. Willsch, M. Villnow, S. Strack, J. R. Weidner, V. Chernogorski, Siemens AG (Germany); S. Lindholm, E. Abromitis, Siemens Power Generation, Inc. (United States); R. Roeding, U. Schwanengel, L. Trefflich, Siemens AG (Germany)

The increasing share of renewables in electric power generation leads to a higher flexibility in the operation of conventional power plants. Especially the component with the highest energy density, the turbo generator, has to face higher demands in efficiency and availability. A careful control of the temperature of the electrical copper leads is necessary to ensure the usual life time of the insulation of about 20 - 30 years. Moreover the movement and vibration of the end windings need to be surveyed to avoid cracks and weakening of the insulation due to mechanical fatigue. As a positive effect the output power during operation can be conditionally increased without the inevitable life time consumption.

Consequently in a new generator design, fibre optic sensors were implemented and during an extensive shop test the design was validated. It was a 370 MVA air cooled turbo generator, equipped with newly designed fibre optic temperature chains implemented on the copper bar directly under the insulation on 8 stator bars. Fibre optic strain sensors monitored the mechanical load of the involutes. Fibre optic proximity sensors monitored the movement of the winding basket and finally fibre optic accelerometers measured the vibration of the end windings. All in all approximately 200 fibre optic measuring points were implemented. During an extensive shop test in Mulheim during July 2011 valuable data were recorded, which validated the new design features.

8370-17, Session 5

Using IFPI sensors for multipoint temperature sensing inside gas turbines

T. Shillig, Virginia Polytechnic Institute and State Univ. (United States)

Due to their compact size, sensitivity, and ability to be multiplexed, IFPI sensors are excellent candidates for almost any multipoint temperature or strain application. This research involved installing a chain of four IFPI sensors onto a 5cm x 5cm coupon. The limited surface area of the coupon presented a unique set of challenges: fiber bending loss, sensor spacing, and fragility issues.

1) Fiber bending loss results in poor signal quality due to reduced fringe contrast. Wavelength-dependent loss in optical fibers also causes noise in the system. Because of these two factors, it is desirable to minimize the number of bends experienced by the fiber, while maximizing the bend radius to the extent allowable by the test environment.

2) However, a second issue that impacts the signal quality is the distance between sensors. After light propagates through the multi-mode fiber (MMF) cavity of an IFPI sensor and is relaunched into a subsequent single-mode fiber, higher order modes are generated. If a second IFPI sensor is located very near to the first, these higher order modes are also launched into the second MMF cavity, and the signal quality is drastically reduced. Because of this, increasing the distance between sensors increases the signal quality.

Given 1) and 2), determining the ideal sensor spacing required careful consideration of both phenomena while taking the inherent fragility of optical fibers into consideration. After thoroughly characterizing both bending loss as well as sensor spacing issues, sensor chains were fabricated, calibrated, and characterized. Each of the sensors had an accuracy of 5 degrees C and a maximum operating temperature of around 600 degrees C, both of which exceeded sponsor expectations. After installation onto a test coupon, these sensor chains were also subjected to high-velocity air in order to prove their robustness.

8370-18, Session 5

Strain insensitive embeddable fiber-optic sapphire high-temperature thermometer

K. DePew, B. Dong, Virginia Polytechnic Institute and State Univ. (United States)

Fiber optic temperature sensing offers significant advantages over electronic sensing in terms of size and insensitivity to harsh environmental conditions, however many fiber optic sensing methods utilize mechanical changes in the optical sensor and therefore suffer from a cross sensitivity between temperature and strain. In this paper, an extrinsic Fabry-Perot interferometer (EFPI) based temperature sensor design suitable for surface mounting or embedding has been developed that exhibits a minimal cross sensitivity with strain. The sensing principle of the EFPI design is well established, and the fabrication method is described in detail. The material choices for the sensor design, including sapphire and zirconia, were selected to meet a high-temperature environmental requirement of greater than 1000° C, and in theory the sensor is capable of operation up to 1700° C. The methods and results of strain cross sensitivity testing are presented and indicate a minimal cross sensitivity between temperature and strain.

8370-19, Session 5

Two-wavelength quadrature multipoint detection of partial discharge in power transformers using fiber Fabry-Perot acoustic sensors

B. Dong, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

A reliable and low cost two-wavelength quadrature interrogating method has been developed to demodulate optical signals from diaphragm-based fiber optic acoustic sensors for multipoint partial discharge detection in power transformers. Commercial available fused silica parts (A fused-silica diaphragm, a piece of fused-silica ferrule) and a cleaved optical single mode fiber were bonded together to form an extrinsic Fabry-Perot acoustic sensor. Two lasers with center wavelengths difference as a quarter of the period of sensor interference spectrum were used to probe acoustic wave induced diaphragm vibration. A coarse wavelength-division multiplexing (CWDM) add/drop multiplexer was used to separate the reflected two wavelengths right before two photo detectors. Optical couplers were used to distribute mixed laser light to each sensor-detector module for multiplexing purpose. Sensor structure, detection system design and experiment results are presented.

8370-30, Poster Session

Improving the in-flight security by employing seat occupancy sensors based on fiber Bragg grating technology

H. Zhang, Univ. of Massachusetts Lowell (United States); P. Wang, Polytechnic Institute of New York Univ. (United States)

The current schemes of detecting the status of passengers in airplanes cannot satisfy the more strict regulations recently released. In basis of investigation on the current seat occupancy sensors for vehicles, in this paper we present a novel scheme of seat occupancy sensors based on Fiber Bragg Grating technology to improve the in-flight security of airplanes. This seat occupancy sensor system can be used to detect the status of passengers and to trigger the airbags to control the inflation of air bags. This scheme utilizes our previous research results of Weight-In-Motion sensor system based on optical fiber Bragg gratings. In contrast to the current seat occupancy sensors for vehicles, this new sensor has so many merits that it is very suitable to be applied in aerospace industry or high speed railway system. Moreover, combined with existing FBG strain or temperature sensor systems built in airplanes, this proposed method can construct a complete airline passenger management system.

8370-31, Poster Session

Implement an adjustable delay time digital trigger for a NI data acquisition card in a high-speed demodulation system

H. Zhang, Univ. of Massachusetts Lowell (United States); L. Fan, Stevens Institute of Technology (United States); P. Wang, Polytechnic Institute of New York Univ. (United States); S. Park, Stevens Institute of Technology (United States)

A NI (National Instruments) DAQ card PCI 5105 is installed in a high-speed demodulation system based on Fiber Fabry-Pérot Tunable Filter. The instability of the spectra of Fiber Bragg Grating sensors caused by intrinsic drifts of FFP-TF needs an appropriate, flexible trigger time. However, the driver of PCI 5105 does not provide the functions of analog trigger type but digital trigger type. Moreover, the high level of trigger signal from the tuning voltage of FFP-TF is larger than the maximum input overload voltage of PCI 5105 card. To resolve this incompatibility,

a novel converter to change an analog trigger signal into a digital trigger signal has been reported previously. However, the obvious delay time between input and output signals in that scheme limit the function of demodulation system. Accordingly, we report an improved low-cost, small-size converter with an adjustable delay time by changing the value of two resistors. This new scheme can decline the delay time to or close to zero when the frequency of trigger signal is less than 3,000 Hz. This method might be employed to resolve similar problems or to be applied in semiconductor integrated circuits.

8370-32, Poster Session

Sound detection monitoring in the transformer oil using fiber optic sensor

J. Lee, Andong National Univ. (Korea, Republic of)

Fiber optic sensors are widely used in the industrial and military fields. To detect partial discharge phenomena generated in transformer oil due to the degradation of electric power facilities, optical fiber sensor technique can be used. To detect external sound signals on the mandrel structure, Sagnac interferometer can be fabricated and tested. Hollow cylinder mandrel used to make fiber optic sensor. Acoustic detection performance of the each sensor was experimented and showed experimental results of the fiber optic sensor arrays in transformer oil under 1kHz. Fiber optic sensors were made by using carbon and teflon mandrel which is hollow cylinder Detected magnitude of the carbon sensor is -51.4dBV and teflon sensor is -69.5dBV. Carbon sensor is more sensitive rather than teflon sensor. It is shown that comparison of the detected signals in air and transformer oil under 3kHz. Carbon sensor in air is less sensitivity than in transformer oil. Because of the density differences of the two fillets of the tank detection difference also comes out. Teflon sensor also has same results like carbon case. In teflon about 53% improvement was found just changing the fillet material. Based on the experimental results sensitivity of the fiber optic acoustic sensor is depended upon the mandrel materials. This system can be expanded to fiber optic health monitoring system in the electric power system.

8370-33, Poster Session

Ultra long distance distributed fiber-optic system for intrusion detection

D. Tu, Ningbo Nuoke Electronic Technology Development Co., Ltd. (China); M. Zhang, Tsinghua Univ. (China); Q. Zou, Z. Jiang, Ningbo Nuoke Electronic Technology Development Co., Ltd. (China); S. Xie, Tsinghua Univ. (China); S. Ren, Ningbo Nuoke Electronic Technology Development Co., Ltd. (China)

This paper research an ultra long distance distributed fiber-optic intrusion detects system based on bidirectional mach-zehnder interferometer. The system has a narrow linewidth laser source and a low noise photodiode amplify module at the each end of the interferometer. The laser source is amplified by a high power EDFA, then input into the mach-zehnder interferometer, and receive at the other end of the fiber. When an intrusion event is act on the fiber, the interference signal is different from the background. The other two communication fibers are used to transmit and receive the high speed synchronous codes. When system detects an intrusion event, recording the codes of the two ends. By measuring the time difference of intrusion signal caused by the event after high speed signal process, the location of the event along the sensing fiber is determined. The challenges of this system are to reduce the nuisance alarm rate and enhance the locating accuracy at ultra long distance. At the present experimental result, system implement the sensing length up to 100km, and the locating accuracy is one thousand of the full length.

8370-20, Session 6

Improvements to high-speed monitoring of events in extreme environments using fiber Bragg grating sensors

E. Udd, Columbia Gorge Research (United States); J. J. Benterou, C. M. May, J. O. Sinibaldi, Lawrence Livermore National Lab. (United States)

Fiber grating sensors have been used to support a wide variety of measurements. This invited paper provides an overview of recent results for these measurements being performed at extremely high speeds and in harsh environments. The duration of the events occur over time spans measured in microseconds and can involve temperatures and pressures associated with the detonation of energetic materials.

8370-21, Session 6

Fiber optic sensors for monitoring the main spire of Duomo di Milano

A. Giussani, F. Roncoroni, M. Scaioni, Politecnico di Milano (Italy)

The incoming restoration work of Duomo di Milano cathedral main spire requires a structural health monitoring. A weight of 90 t due to scaffoldings was applied to the dome and a complex monitoring system was designed in order to measure the deformation of the church and its spire. The paper gives a presentation of the different methods used to investigate the different structural components including: optical leveling, robotic total stations, accelerometers, strain gauges, optical plumbs, clinometre, and extensometre. In particular for the analysis of structural elements at higher risk of collapse, fiber optic sensors were selected, based on FBG (Fiber Bragg Grating) technology. Strain of the lower part of the vaulting-rigs inside the octagonal doom is the measurement of interest. As the expected signals are very small and the thermal disturbances very significant, a thermal characterization of two types of commercial strain gauges was carried out in laboratory with a thermal chamber. A block of the same marble used for the cathedral was tested. This allowed to find a relationship to be used later to compensate for any thermal effects. Finally, some sensors are placed at critical points to record real time deformation measurements. A central control unit will host an alarm system and GUI to show all results.

8370-22, Session 6

Ultrasonic detection based on pi-phase shifted fiber Bragg grating

M. Han, T. Fink, Q. Zhang, W. Ahrens, F. Guo, Univ. of Nebraska-Lincoln (United States)

We present a highly sensitive fiber-optic ultrasonic sensor based on pi-phase-shifted Fiber Bragg gratings (piFBG) for structure health monitoring. Due to the phase discontinuity at the center of the grating, the reflection spectrum of a piFBG features a narrow notch, leading to significantly improved sensitivity over traditional fiber-Bragg-grating (FBG) based ultrasonic sensors. We show the advantages of piFBG over FBGs for ultrasonic detection in terms of frequency bandwidth and sensitivity. We study the performance of piFBGs for detection of pressure waves and Lamb waves and show that key performance parameters including sensor sensitivity and directivity are significantly different for detection of different types of ultrasonic waves. The effect of light polarization on sensor sensitivity for Lamb wave detection is also studied. The performance of a piFBG sensor system is tested and compared with a conventional piezoelectric ultrasonic sensor system. The noise performance of the piFBG sensor system is theoretically and experimentally analyzed.

8370-23, Session 6

A design of low power consumption and high speed WDM-to-OTDM waveband conversion system for the future optical sensing networks

T. Yang, Y. Peng, D. Jia, Z. Wang, M. Sang, Tianjin Univ. (China)

There is an inherent conflict between the extension of sensing networks with a number of fiber Bragg grating (FBG) sensors and the limited bandwidth of optical fiber amplifier. One of solutions for this issue is digitizing the reflected spectrum from the FBG sensors by using an optical comb filter so that the digitized data at the same time with wavelength-division multiplex (WDM) format can be and has to be converted to an optical time-division multiplexing (OTDM) data carried on a single wavelength by a multi-wavelength or waveband conversion method for the sake of using the limited spectrum resource effectively. Among the methods and devices for waveband conversion at fairly high bit rate, electroabsorption modulators (EAMs) that are based on its effects of cross-amplitude modulation (XAM) and cross-phase modulation (XPM), can offer moderate fast conversion ability with quite low optical input power requirements compared to the other kinds of devices, such as optical semiconductor amplifiers, high nonlinear fibers. In this paper, a compact WDM-to-OTDM conversion system is designed in which a commercial 40 GHz EAM is the key device for converting the time-delayed at equal interval multi-wavelength optical signals of a frame of WDM data to an OTDM signal. A polarization discriminated delayed-interferometer is introduced to the system for reducing the negative effects of the long recovering time of EAMs in order to be able to deal with the high bit-rate data by utilizing EAMs effectively as much as possible. A simple dispersion flat fiber (DFF) is used in the system for delaying the WDM signals at equal time interval, precisely, and makes the whole system compact without conventional complicated space-separated time delay arrangements in which a waveguide array grating (WAG) and many fibers with different lengths are needed.

8370-25, Session 7

Performance limitations of a white light extrinsic Fabry-Perot interferometric displacement sensor

E. A. Moro, M. D. Todd, Univ. of California, San Diego (United States); A. Puckett, Los Alamos National Lab. (United States)

Non-contacting interferometric fiber optic sensors offer a minimally invasive, high-accuracy means of measuring a structure's kinematic response to loading. The performance of interferometric sensors is often dictated by the technique employed for demodulating the kinematic measurand of interest from phase in the observed optical signal. In this paper a white-light extrinsic Fabry-Perót interferometer is implemented, offering robust displacement sensing performance. Displacement data is extracted from an estimate of the power spectral density, calculated from the interferometer's received optical power measured as a function of optical transmission frequency, and the sensor's performance is dictated by the details surrounding the implementation of this power spectral density estimation.

One advantage of this particular type of interferometric sensor is that many of its control parameters (e.g., frequency range, frequency sampling density, sampling rate, etc...) may be chosen so that the sensor satisfies application-specific performance needs in metrics such as bandwidth, axial displacement range, displacement resolution, and accuracy. A suite of user-controlled input values is investigated for estimating the spectrum of power versus wavelength data, and the relationships between performance metrics and input parameters are described in an effort to characterize the sensor's operational performance limitations. A comparison is drawn between the capabilities of this sensing approach and those of a recently proposed intensity-modulated displacement sensor, whose architecture has been optimized for operation over a particular axial displacement range.

8370-26, Session 7

Distributed sensing of vibration, temperature, and pressure using fiber optics

P. Kung, QPS Photronics Inc. (Canada)

National Borders are a security issue for all Governments and porous Borders can lead to smuggling of people, drugs, weapons and contraband, which help fund criminal activity and can lead to severe social problems across the globe.

In order for Governments to protect the nation state and their citizens it is vitally important that they control their Borders effectively. However, this can often present quite a challenge as Borders may run for hundreds if not thousands of kilometers through varying and sometimes hostile terrain.

This paper discusses a buried distributed sensor solution based on the detection of acoustic activities. It effectively monitors and detect intrusion and or subversive activities like planting of road side bomb during the night, or the clandestine activities of tunnel digging underneath the earth for the smuggling of arms , drugs or illegal immigrants. The Border Guard solution works on phonons or perturbations where cables can be buried covering up to 20 kilometers of area. The cables are buried at least 6 to 8 inches beneath the soil. The cables contain no metallic parts so it would be difficult to detect the layout using metal detectors. Each interrogation box is linked up to a secure network where monitoring can be performed at a remote location covering hundreds and thousands of kilometers of hostile terrain.

The system is also equipped with sensitivity control to overcome the problem of false alarm and rely on complex signature analysis to identify the nature of the intrusion events.

8370-27, Session 7

Mach-Zehnder interferometer for movement monitoring

V. Vasinek, J. Cubik, S. Kepak, J. Doricak, J. Latal, P. Koudelka, Technical Univ. of Ostrava (Czech Republic)

Fiber optical interferometers belong to highly sensitive equipments that are able to measure slight changes like distortion of shape, temperature and electric field variation and etc. Their great advantage is that they are insensitive on ageing component, from which they are composed of. It is in virtue of herewith, that there are evaluated no changes in optical signal intensity but number interference fringes. To monitor the movement of persons, eventually to analyze the changes in state of motion we developed method based on analysis the dynamic changes in interferometric pattern. We have used Mach- Zehnder interferometer with conventional SM fibers excited with the DFB laser at wavelength of 1550 nm. It was terminated with optical receiver containing InGaAs PIN photodiode. Its output was brought into measuring card module that performs on FFT of the received interferometer signal. The signal rises with the composition of two waves passing through single interferometer arm. The optical fiber SMF 28e in one arm is referential; the second one is positioned on measuring slab at dimensions of 1x2m. A movement of persons around the slab was monitored, signal processed with FFT and frequency spectra were evaluated. They rose owing to dynamic changes of interferometric pattern. The results reflect that the individual subjects passing through slab embody characteristic frequency spectra, which are individual for particular persons. The scope of measuring frequencies proceeded from zero to 10 kHz. It was also displayed in experiments that the experimental subjects, who walked around the slab and at the same time they have had changed their state of motion (knee joint fixation), embodied characteristic changes in their frequency spectra. At experiments the stability of interferometric patterns was evaluated as from time aspects, so from the view of repeated identical experiments. Two kinds of balls (tennis and ping-pong) were used to plot the repeatability measurements and the gained spectra at repeated drops of balls were compared. Those stroked upon the same place and from the same elevation and dispersion of the obtained frequency spectra was evaluated. These experiments were performed on the series of 20 repeated drops from highs of 0,5 and 1m. The evaluation of experiments displayed that the dispersion of measured values is lower than 4%. Frequency response has been verified with the loudspeaker connected to signal generator and amplifier. Various slabs have been measured and frequency ranges were compared for particular slab designs.

8370-28, Session 7

Fiber Fizeau interferometer for remote passive sensing

J. Bush, K. Suh, Optiphase, Inc. (United States)

An intrinsic fiber Fizeau remote, passive interferometric sensing approach is presented. This approach has capabilities of high frequency response (100's of KHz), large, linear dynamic range and low noise. The interrogation technique involves a phase generated carrier with local modulation, and an embedded optical phase demodulator configured for polarization diverse reception and large angle demodulation. Linear dynamic range easily exceeds 120 dB. The design approach enables the sensor and lead-in assembly to be completely passive and allows for sensing in rugged environments (wide range thermal, high hydrostatic pressure). The lead-in fiber may be of arbitrary length (up to many km), and the sensor packaging contains partial reflectors internal to the fiber. Applications include embedded sensors, line sensors, or mechanically adapted for acoustic, pressure, vibration, acceleration or seismic sensing. This development focused on low cost realizations that do not compromise sensor / measurement performance.

8370-29, Session 7

Interferometric polymer optical sensor for intravascular optoacoustic imaging

D. C. Gallego, Univ. Carlos III de Madrid (Spain); M. Wang, Univ. of Oulu (Finland); J. Hiltunen, VTT Technical Research Ctr. of Finland (Finland); M. Kinnunen, R. Myllyla, Univ. of Oulu (Finland); H. R. Lamela Rivera, Univ. Carlos III de Madrid (Spain)

Recent advances in ultrasound and optoacoustic imaging techniques for clinical applications demands for miniaturized and wide bandwidth ultrasonic probes. In this work we present the ultrasonic probe of an optoacoustic intravascular endoscope based on an interferometric polymer optical channel waveguide ultrasonic sensor. We compare experimentally its sensitivity, dynamic range, frequency bandwidth, spatial resolution and compactness with two single-mode fiber optic sensors based on silica and polymer. All sensors are designed for detection of optoacoustic wave sources with frequencies in the megahertz range. These results are also compared with a PVDF ultra wideband sensor.

8370-34, Session 7

Specialty fiber design for commercial, intrinsic fiber sensors

C. Emslie, Fibercore Ltd. (United Kingdom)

After 30 years of promise, Fiber Sensors are at last beginning to achieve commercial acceptance, with many thousands of Fiber Optic Gyroscopes already in service, geophone webs and towed hydrophone arrays finding favour within both the oil and defence industries and the Faraday-effect current sensor enjoying something of a renaissance.

Despite heavy emphasis on the use of conventional, telecoms-type fibers, primarily for reasons of cost, the use of so-called 'Specialty Fibers' in which additional functionality has been engineered into the fiber itself dramatically increases both the breadth of application and also the performance of the sensor itself.

The paper reviews the development of a range of 'Specialty Fibers' , including various adaptations of polarisation maintaining, bend-insenstive and rare-earth-doped fibers, puts them within historical and economic contexts and, where direct comparison is valid, compares and contrasts their performance with that of more conventional fibers.

The paper also acknowledges the contribution to overall sensor performance provided by both coating / buffer and cable characteristics - an aspect that has often been neglected, over-shadowed by what has been viewed as the more 'technical' aspects of fiber design and fabrication.

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8371A-01, Session 1

New imaging and sensing architectures for telemedicine and global healthcare

A. Ozcan, Univ. of California, Los Angeles (United States)

Despite the rapid progress and the recent renaissance that we have been experiencing in optical microscopy and imaging, most of the advanced imaging modalities still require complex and costly set-ups that unfortunately limit their use beyond well equipped laboratories. In the meantime, microscopy and diagnostics in resource-limited settings have requirements significantly different from those encountered in advanced laboratories, and such imaging devices should be cost-effective, compact, light-weight, and appropriately accurate to be usable by minimally trained personnel. Towards this end, here we present an on-chip cytometry platform that utilizes cost-effective and compact components to enable digital recognition and microscopic imaging of cells with sub-cellular resolution over a large field of view without the need for any lenses, bulky optical components or coherent sources such as lasers. This holographic imaging and diagnostic modality has orders of magnitude improved light collection efficiency and is very robust to misalignments which eliminates potential imaging artifacts or the need for realignment, making it highly suitable for field use. We demonstrate the performance of this platform for microscopic imaging and automated counting of whole blood cells with minimal sample preparation steps yielding spatial information at the sub-cellular level. Because this platform utilizes compact and cost-effective components that are also misalignment tolerant it may provide an important toolset for telemedicine based cytometry and diagnostics applications especially in resource poor settings for various global health problems such as malaria, HIV and tuberculosis.

8371A-02, Session 1

Lab-on-a-cellphone: emerging platform for telemedicine global health

O. Mudanyali, D. Tseng, C. Oztoprak, S. O. Isikman, I. Sencan, O. Yaglidere, A. Ozcan, Univ. of California, Los Angeles (United States)

Number of mobile-phone subscriptions has reached 5 billion by 2011 and the majority of the mobile-phones are being used in the developing countries, according to International Telecommunication Union (ITU). This massive volume brings an enormous cost-reduction to mobile -phones despite their sophisticated hardware/software capabilities. Therefore, utilizing the advanced state-of-the-art of the mobile-phone technology towards microscopic imaging and point-of-care diagnostics can offer numerous opportunities to improve healthcare especially in the developing world, where medical facilities and infrastructure are extremely limited or even do not exist.

Toward this end, we introduce a lensfree mobile-phone microscope which achieves subcellular spatial resolution over an imaging field-of-view that is >10 times larger than conventional microscopes, providing an ancillary telemedicine tool to rapidly screen various bodily fluids such as blood, urine, sputum, etc. as well as water samples even in remote locations. This platform does not require any bulky and costly opto-mechanical components, i.e., an inexpensive hardware attachment, that is only ~38 grams, is needed to perform lensless microscopy on a commercially-available mobile-phone. This mobile-phone microscope utilizes a simple light-emitting-diode together with a large pinhole to record lensfree holographic images of the samples using the installed CMOS sensor of the mobile-phone. Acquired holographic images are then digitally processed using custom-developed reconstruction algorithms to rapidly create microscopic images of the specimen. This lensfree mobile-phone microscope may provide a powerful telemedicine tool for improved healthcare delivery in resource-limited settings, and can potentially contribute to surveillance of various preventable epidemics to decrease the number of casualties in third-world countries.

8371A-03, Session 1

On-chip blood analysis using lensless microscopy

S. O. Isikman, S. Seo, I. Sencan, O. Mudanyali, T. Su, A. Erlinger, A. Ozcan, Univ. of California, Los Angeles (United States)

Despite the availability of advanced toolsets to perform whole blood analysis such as flow-cytometers and light-microscopes, these instruments are in general restricted for use in advanced laboratories owing to their large size and complexity. On the other hand, blood analysis in low-resource settings requires compact, lightweight and cost-effective devices that can be operated and maintained by minimally trained personnel. To this end, lensfree on-chip microscopy offers a promising alternative as a field-deployable blood analysis tool by providing sub-micrometer spatial resolution over an ultra wide field-of-view (FOV). Here we demonstrate the application of lensless imaging for automated high-throughput whole blood analysis, which can provide a significant solution for rapid medical diagnosis in resource-limited environments.

In lensfree imaging with pixel super-resolution, simple LEDs are utilized to record multiple slightly shifted holographic images of the sample (e.g. a blood smear slide) over the entire active area of the sensor-array (i.e., ~24mm2). These shifted holographic images are first digitally combined to synthesize a single high-resolution hologram, which can then be rapidly reconstructed to obtain microscopic images of the cells. We demonstrate accurate automated counting of red-blood-cells (RBCs) at densities reaching ~0.4 Million cells/μL. together with volume and hemoglobin density characterizations of the RBCs. Further, we demonstrate automated counting of white-blood-cells (WBCs) as well as imaging of WBCs with sufficient resolution to differentiate granulocytes, monocytes and lymphocytes from each other towards 3-part differential counts. The same platform is also shown to be effective in detecting Malaria infected red blood cells on standard thin blood smears.

8371A-04, Session 1

Field-portable fertility test using lensless microscopy on a chip

T. Su, A. Erlinger, D. Tseng, A. Ozcan, Univ. of California, Los Angeles (United States)

The mean sperm counts in Western countries have consistently decreased by ~50% during the last 50 years. However, there is currently no automated technology that can affordably support long-term and large-scale quantified field surveys on male fertility outside of advanced laboratories in order to better isolate the potential factors to this global-trend. To provide a feasible solution for this task, here we demonstrate a compact and light-weight platform to conduct automated semen analysis using a field-portable lensfree on-chip microscope. This holographic on-chip imaging platform weighs ~46 grams, measures ~4.2 x 4.2 x 5.8 cm, and does not require any lenses, lasers or other bulky optical

components to achieve phase and amplitude imaging of sperms over ~24 mm^2 FOV with an effective numerical aperture of ~0.15-0.2. Using this wide-field lensfree computational microscope, semen samples are imaged for ~10 seconds, capturing a total of ~20 lensfree holographic frames. Digital subtraction of these consecutive lensfree frames, followed by appropriate processing of the reconstructed phase images, enables automated quantification of the count, the speed and the dynamic trajectories of motile sperms, while summation of the same frames permits counting of immotile sperms. Also note that ~24 mm^2 FOV of our lensfree on-chip imaging platform is >100 fold larger than the FOV of a typical 20X objective-lens. Such a compact and light-weight automated semen analysis platform running on a wide-field lensfree on-chip microscope could be especially important for fertility clinics, personal male fertility tests for evaluating influence of long-term radiation or chemical exposure on male fertility.

8371A-05, Session 1

Recent advances in the use of laser-induced breakdown spectroscopy (LIBS) as a rapid point-of-care pathogen diagnostic

S. J. Rehse, Univ. of Windsor (Canada); A. W. Miziolek, US Army Research Lab. (United States)

In the last five years, laser-induced breakdown spectroscopy (LIBS) has made tremendous progress in becoming a viable technology for rapid bacterial pathogen detection and identification. LIBS significant advantages include speed (< 1 sec analysis), portability, robustness, lack of consumables, little to no need for sample preparation, lack of genetic amplification, and the ability to identify all bacterial pathogens without bias (including spore-forms and viable but non-culturable specimens). The US Army has been working with industry to develop advanced benchtop and field-portable LIBS devices, and thus this technology could be implemented in doctors' offices, clinics, or hospital laboratories for point-of-care medical specimen analysis; mounted on military medical robotic platforms for in-the-field diagnostics; or used in stand-off configuration for remote sensing and detection.

In this talk, we will present the latest advances achieved in LIBS-based bacterial sensing. We have uniquely identified species from over five bacterial genera with high-sensitivity and specificity. We have shown that bacterial identifications are completely unaffected by environment, nutrition media, or state of growth. We have shown that accurate diagnosis can be made on autoclaved or UV-irradiated specimens. Efficient discrimination of bacteria at the strain level has been demonstrated. A rapid urinary tract infection diagnosis has been simulated with no sample preparation and a one second diagnosis of a pathogen surrogate has been demonstrated using advanced chemometric analysis with a simple "stop-light" user interface. As well, stand-off bacterial identification at a 20-m distance has been demonstrated on a field-portable instrument.

8371A-06, Session 1

e-nanoflex point-of-care sensor system: smartphone-based roaming health monitor

V. K. Varadan, Univ. of Arkansas (United States)

POC diagnostics for neurological, metabolic and cardiovascular disorders require constant long term un-tethered monitoring of individuals. Given the uncertainty associated with location and time at which immediate diagnosis and treatment may be required, constant vigilance and monitoring is the only practical solution. What is needed is for a remote cyber-enabled health care smart system incorporating novel ideas from nanotechnology, low power embedded systems, wireless networking and cloud computing, to fundamentally advance. To meet this goal, we present e-Nanoflex platform which is capable of monitoring patient health wherever they may be and communicating the data in real-time to a physician or a hospital. Using nanostructured sensors, e-Nanoflex provides nearly invisible monitoring of physiological conditions. It relies on smartphones to filter, compress, and relay geo-tagged data. Further, it ties to a backend cloud infrastructure for data storage, data dissemination, and abnormality detection using machine learning techniques. e-Nanoflex is a complete end-to-end system for physiological sensing and geo-tagged data dissemination to hospitals and caregivers. It is intended as a basic platform that can support any nanostructure based flexible sensors to monitor a variety of conditions such as body temperature, respiration air-flow, oxygen consumption, bioelectric signals, pulse oximetry, muscle activity, and neural activity.

8371A-09, Session 1

Commercial development of high sensitivity quantitative rapid immunoassay systems for detection of biological agents

B. J. O'Farrell, Diagnostic Consulting Network (United States)

No abstract available

8371A-10, Session 2

On-demand molecular diagnostic systems for tuberculosis: from inception to clinical impact

D. Alland, Univ. of Medicine & Dentistry of New Jersey (United States)

Until recently tuberculosis required many weeks to diagnose. The new Cepheid Xpert MTB/RIF assay has changed this paradigm, providing on-demand point-of-care tuberculosis detection and identification of rifampin-resistance in approximately two hours. The integrated assay cartridge containing both dry and liquid reagents, permits virtually hands-free operation and minimal training. Analytic studies have demonstrated excellent sensitivity and specificity in tests directly from patient sputum samples. Clinical studies have demonstrated that the assay improves time to detection, and critically, time to treatment. Despite the performance of the assay, there remains a need to expand detection to drug-resistance other than rifampin and to improve detection in challenging non-sputum sample types such as blood, CSF and stool. We are addressing these needs with advanced probe design and detection methods.

8371A-11, Session 2

Breath-based biomarkers for tuberculosis

A. H. J. Kolk, Univ. van Amsterdam (Netherlands); J. J. N. van Berkel, Maastricht Univ. (Netherlands); M. M. Claassens, L. Walters, Stellenbosch Univ. (South Africa); S. Kuijper, Univ. van Amsterdam (Netherlands); J. W. Dallinga, F. Van Schooten, Maastricht Univ. (Netherlands)

We investigated the potential of breath analysis by gas chromatography - mass spectrometry (GC-MS) to discriminate between samples collected prospectively from patients with suspected tuberculosis (TB). Samples were obtained in a TB endemic setting in South Africa where 34% of the culture proven TB patients had a Ziehl-Neelsen (ZN) negative sputum smear. A training set of breath samples from 60 sputum culture proven TB patients and 76 culture negative non-TB patients was analyzed by GC-MS. A classification model with 7 compounds resulted in a training set with a sensitivity of 72%, specificity of 86% and accuracy of 79% compared with culture. The classification model was validated with an independent set of breath samples from 21 TB and 50 non-TB patients. A sensitivity of 44%, specificity of 84% and accuracy of 76% was found. We conclude that the 7 VOCs that discriminate breath samples from TB and non-TB patients in our study population are probably host-response related VOCs and are not derived from the VOCs secreted by M.

tuberculosis. It is concluded that at present that GC-MS breath analysis is able to differentiate between TB and non-TB breath samples even among patients with a negative ZN sputum smear but a positive culture for M. tuberculosis. Further research is required to improve the sensitivity and specificity before this method can be used in routine laboratories.

8371A-13, Session 2

Rapid HIV tests for developing countries: the challenge of false-negative tests

R. Yogev, Children's Memorial Hospital (United States)

No abstract available

8371A-16, Session 2

Simple and affordable point-of-care HIV staging enabled by controlled reagent release from gelatin

M. Beck, N. van der Velde, S. Brockhuis, D. Wasserberg, L. W. M. M. Terstappen, Univ. Twente (Netherlands)

The CD4 count, i.e. the concentration of CD4+ T-lymphocytes (helper T-cells) in the blood is a good indicator of the disease progression of an HIV infection. It is used especially in the low-income countries affected most by HIV to decide on the treatment with antiretroviral therapy and to measure its effectiveness. The standard method to determine the CD4 count, flow cytometry, does not meet the requirements in many rural areas with insufficient infrastructure to operate these expensive and sensitive machines or to ship blood samples to a central lab. An affordable and easy-to-use test is needed to provide CD4 counting for these areas.

We have developed a simple point-of-care test for CD4 counting which does not require any sample preparation. Microfluidic counting chambers contain a reagent coating which releases fluorochrome-conjugated antibodies after the chambers are filled with whole blood from a finger prick. After an incubation time of 30 min, the CD4 count is obtained with a simple, compact, portable, battery-operated image cytometer. Automatic cell counting in images representing more than 1 µl of whole blood correlates well with flow cytometry.

The fabrication of these counting chambers is relatively simple and the used materials cheap, making affordable diagnostics even in the poorest regions of Africa appear feasible.

8371A-17, Session 2

Hepcidin: new biomarker for global health diagnostics of anemia and infection

M. Westerman, Intrinsic LifeSciences, LLC (United States)

No abstract available

8371A-18, Session 2

Enzymatic glucose detection using ZnO nanorods modified gate graphene transistor

S. C. Hung, C. W. Chen, National Central Univ. (Taiwan); Y. C. Lai, B. S. Wu, National Chiao Tung Univ. (Taiwan); Y. H. Chien, Y. P. Huang, National Central Univ. (Taiwan); G. C. Chi, National Chiao Tung Univ. (Taiwan); F. Ren, S. J. Pearton, Univ. of Florida (United States)

ZnO nanorod-gated graphene transistors are demonstrated for the detection of glucose. A ZnO nanorod array was selectively grown on the gate area using low temperature hydrothermal decomposition to immobilize glucose oxidase (GOx). The one-dimensional ZnO nanorods provide a large effective surface area with high surface-to-volume ratio and provide a favorable environment for the immobilization of GOx. Graphene transistors are made by graphene grown by chemical vapor deposition (CVD) transferred on a glass covered with a thin SiO_2 layer on the gate area. The ZnO nanorod matrix on the gate area provides a microenvironment for immobilizing negatively charged GOx while retaining its bioactivity, and passes charges produce during the GOx and glucose interaction to the graphene transistor. Further details will discussed in the conference.

8371A-39, Session 2

Mathematical model for Dengue with three states of infection

J. F. Ospina, Univ. EAFIT (Colombia)

We analyze a mathematical model for the transmission of the dengue disease with three classes of infectious individuals: asymptomatic, partially symptomatic and fully symptomatic. In the model, the "boson vector" is the Aedes aegypti mosquito; the human populations is divided into five classes : susceptible, asymptomatic infectious, partially symptomatic infectious, fully symptomatic infectious and recovered. The boson vector population is divided in three classes: susceptible, infectious and recovered. It is showed that he disease free state is locally asymptotically stable if and only if R0 1. We show that the formulation of quantum models for the infectiousness is a forward step in the understanding of the disease propagation using mathematical models. It is expected that such quantum models will be useful in the analysis of propagation of air-borne diseases and more complex vector-borne diseases.

8371A-71, Session 2

Challenges in point-of-care diagnostics in infectious disease

J. Jackman, Johns Hopkins Univ. Applied Physics Lab. (United States)

No abstract available

8371A-74, Session 2

Droplet digital PCR--a breakthrough in quantitative PCR: applications for HIV and STD testing

No abstract available

8371A-19, Session 3

DARPA challenge: developing new technologies for brain and spinal injuries

C. Macedonia, Defense Advanced Research Projects Agency (United States); G. S. F. Ling, Uniformed Services Univ. of the Health Sciences (United States); M. Zamisch, Science and Technology Associates, Inc. (United States); J. W. Judy, Defense Advanced Research Projects Agency (United States) and Univ. of California, Los Angeles (United States)

No abstract available

8371A-20, Session 3

Clinical white matter damage detection in military and civilian TBI

D. O. Okonkwo, Univ. of Pittsburgh Medical Ctr. (United States)

No abstract available

8371A-21, Session 3

Brain tissue mapping and neuroprosthetic devices

W. Shain, Seattle Children's Research Institute (United States); B. Roysam, Univ. of Houston (United States)

No abstract available

8371A-22, Session 3

High-resolution brain scanning technology for advanced TBI diagnostics

J. Onton, Univ. of California, San Diego (United States)

No abstract available

8371A-23, Session 3

Biomarkers for diagnostics of traumatic brain injury

K. Wang, Univ. of Florida, McKnight Brain Institute (United States)

No abstract available

8371A-24, Session 3

Saliva biomarkers for noninvasive diagnostics: applications for TBI, PTSD and environmental medicine

S. O. Southern, Gaia Medical Institute (United States)

We have developed a large panel of saliva-based biomarkers (n=100) for noninvasive disease diagnostics. The biomarkers can be measured using a rapid hand-held test. Current applications of the technology include diagnostics of post-traumatic stress disorder (PTSD) and post-concussional disorder (mTBI/PTSD). Warfighters engaged in current military operations are sustaining mTBI/PTSD and PTSD at unprecedented rates of nearly 20%. A rapid saliva test avoids the stigma associated with psychological testing and facilitates early treatment, faster return to duty and reduced complications. Another application is diagnostics of dehydration. Proper fluid balance is critical for Warfighter performance and health. Dehydration is one of the fundamental physiological mechanisms of illness and injury in extreme environments such as Iraq or Afghanistan. Over aggressive re-hydration can cause serious health problems such as hyponatremia. A field-expedient rapid saliva test will allow noninvasive hydration management during training and combat.

8371A-25, Session 3

Handheld device for rapid TBI diagnostics

S. Kumar, SFC-Fluidics (United States)

No abstract available

8371A-26, Session 3

Perspectives on mTBI and PTSD diagnostics in the Navy

R. N. McLay, Naval Medical Ctr. San Diego (United States)

No abstract available

8371A-27, Session 3

Emerging treatments for PTSD based on virtual reality software

T. Talbot, The Univ. of Southern California (United States)

No abstract available

8371A-69, Session 3

EYE-TRAC: monitoring attention and utility for mTBI

J. Ghajar, J. Maruta, J. Tong, Z. Iqbal, A. Schonberger, Brain Trauma Foundation (United States)

Attention is a core function in cognition and also the most prevalent cognitive deficit in mild traumatic brain injury (mTBI). Predictive timing is an essential element of attention functioning because sensory processing and the execution of goal-oriented behavior are facilitated by temporally accurate prediction. It is hypothesized that impaired synchronization between prediction and external events accounts for the attention deficit in mTBI. Other cognitive symptoms and somatic or affective symptoms associated with mTBI may be explained as secondary consequences of impaired predictive timing. Eye-Tracking Rapid Attention Computation (EYE-TRAC) quantifies predictive timing using indices of dynamic visuo-motor synchronization (DVS) between the gaze and the target during continuous predictive visual tracking. Such quantification allows for comparison of an individual's cognitive performance to a normative standard as well as detection of day-to-day changes within individuals. We report preliminary results of normative data and data collected from subjects with a history of mTBI (tested within 2 weeks of an injury that resulted in a loss of consciousness under 30 min and post-traumatic amnesia under 24 h) and post-concussive symptoms at the time of recruitment. The proportion of mTBI subjects with DVS worse than 95% of normal subjects was substantial. Monitoring of subjects from an acute stage to recovery indicated that an initial abnormal DVS tended to be followed by improvement into the normal range. In summary, EYE-TRAC provides fast and objective indices for cognitive performance that may be useful for assessing mTBI-related attention impairments and monitoring of the recovery process.

8371A-28, Session 4

TATRC challenge: developing new technologies for combat casualty care

S. Cardin, Carnegie Mellon Univ. (United States)

No abstract available

8371A-30, Session 4

3D medicine: streaming video-based 3D reconstruction method compatible with existing monoscopic and stereoscopic endoscopy systems

H. Bouma, W. van der Mark, TNO Defence, Security and Safety (Netherlands); P. Eendebak, TNO Defense, Security and Safety (Netherlands); S. Landsmeer, A. W. M. van Eekeren, F. B. ter Haar, F. P. Wieringa, TNO Defence, Security and Safety (Netherlands); J. v. Basten, Canisius Wilhelmina Hospital (Netherlands)

Compared to open surgery, minimal invasive surgery (MIS) offers many advantages, such as reduced trauma and scarring, less pain and complications, faster recovery and shorter hospitalization time. However, indirect viewing with an endoscope limits orientation and space perception during MIS. Surgeons must build a mental 3D-model from sequentially scanned anatomical details. Stereo-endoscopy (e.g. using the Da Vinci robot) improves depth perception, but still only offers stereopsis within the direct endoscopic field-of-view.

We describe a novel technology that can reconstruct 3D panoramas from video streams of endoscopically explored body cavities. The method is basically compatible with any endoscope and provides a much wider cumulative overview than single endoscopic image frames can offer. The technology is an add-on to existing endoscopy systems. It does not need position tracking, additional markers or expensive (MR or CT) pre-scans, because it is purely based on information that is extracted from the endoscopic images.

We demonstrate photorealistic 3D environments generated from single channel (mono) and dual channel (stereo) laparoscopic video data. To assist in navigation, the method can visualize position and orientation of the endoscope relative to the environment as viewed from a perspective outside the endoscope. The method also allows accurate measurement of distances and sizes. The resulting 3D reconstructions can be directly applied in endoscopic simulators and e-learning. Extended to real-time processing, the method looks promising for telesurgery or other remote vision-guided tasks requiring spatial visualization and complex navigation.

8371A-31, Session 4

Exploitation of pulse and respiration signals from the SimMan3GTM patient simulator using a laser Doppler vibrometer (LDV)

K. A. Byrd, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Modeling and Simulation provides a safe and close-to-realistic environment to predict and analyze the performance of both humans and sensor systems. Models are developed after a series of controlled laboratory experiments and then verified and validated (V&V) through field tests in uncontrolled, outdoor testing environments. After successful V&V, simulations are built and used as training tools. In the medical community, patient simulators (simulation mannequins) are used as education and training tools for nurses and medics. Students have the opportunity to perform actual medical procedures including the diagnosis and treatment of patient conditions such as hypovolemic shock. A new thrust for the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD), Human Signature Exploitation (HSE) Branch, is the use of remote sensing technologies to detect human vital signs at standoff distances. This capability will provide medics with the ability to diagnose while under fire in addition to helping them to prioritize the evacuation of casualties off the battlefield.

A potential alternative (or precursor) to human subject testing is the use of simulation mannequins. This substitution provides a safe and cost effective means to develop, test, and evaluate (benchmark) sensors without putting any human subjects at risk. In this paper, we present our work on using a Laser Doppler Vibrometer (LDV) to exploit pulse signals from a SimMan3GTM patient simulator. Results indicate that our LDV sensor system is capable of exploiting and making measurements from discernable pulse signals taken off the patient simulator at standoff (8 meters).

8371A-32, Session 4

Scar-free skin regeneration: new technology for burn treatment

S. Gerecht, Johns Hopkins Univ. (United States)

No abstract available

8371A-33, Session 4

Stem cell engineering for tissue repair: new approach to TBI treatment

N. Zhang, Clemson Univ. (United States)

No abstract available

8371A-35, Session 4

Antimicrobial resistance determinant microarray for analysis of multi-drug resistant isolates

C. R. Taitt, T. A. Leski, G. J. Vora, U.S. Naval Research Lab. (United States); B. House, M. Nicklasson, G. Pimentel, Naval Medical Research Unit-3 (Egypt); D. V. Zurawski, B. Kirkup, Walter Reed Army Institute of Research (United States); D. W. Craft, Walter Reed Army Institute of Research (Retired) (United States); E. Lesho, P. Waterman, Walter Reed Army Institute of Research (United States)

The prevalence of multidrug-resistant infections in personnel wounded in Iraq and Afghanistan has made it challenging for physicians to choose effective therapeutics in a timely fashion. To address the challenge of identifying the potential for drug resistance, we have developed the Antimicrobial Resistance Determinant Microarray (ARDM) to provide DNA-based analysis for over 250 resistance genes covering 12 classes of antibiotics. Over 70 drug-resistant bacteria from Egypt and Iraq/Afghanistan have been analyzed on ARDM, with significant differences in patterns of resistance identified: genes for resistance to sulfonamides, trimethoprim, chloramphicol, rifampin, and MLS drugs were more frequently identified in Iraq/Afghanistan isolates. Of particular concern was the presence of genes directed against many of the last-resort antibiotics used to treat war trauma-associated infections.

8371A-36, Session 4

Field-expedient health assessment using a rapid biomarker test

M. Westerman, Intrinsic LifeSciences, LLC (United States)

No abstract available

8371A-38, Session 4

Nanosensing platforms: physics, technology and applications

E. Carlen, University of Twente (Netherlands)

There has been a sharp increase in reports of ultrasensitive sensors over the past few years based on nanoscale structures and devices such as nanowires (NW), carbon nanotubes (CT), nanoparticles, and nanocantilever beams. One-dimensional electronic structures, such as NW and CT, are particularly compelling due to their potential for biosensing applications and suitability for large-scale high-density integration. NW devices are advantageous compared to CT devices because they are fabricated from materials, such as Si, with a vast knowledge base of material properties, mature fabrication technologies and techniques for surface passivation and modification. Si-NW sensors have recently attracted a large amount of attention due largely to the reported high label-free detection sensitivities of biomolecular binding in aqueous phase with an all-electrical readout in real-time. Nanoscale plasmonic devices is another class of highly sensitive biosensors that exploit localized surface plasmon resonances of metal nanostructures, such as colloidal nanoparticles and nanotextured surfaces, for the detection of surface adsorbed molecules or ligand-ligate binding using absorption spectroscopy or Raman spectroscopy, for example. Surface enhanced Raman scattering (SERS) is a particularly interesting phenomena that improves the scattering efficiency of inelastically scattered photons that results in measurable intensities of molecular vibrational spectra of low concentrations of surface adsorbed molecules that can be used for molecular identification and in some cases biosensing applications. In this talk I will present our latest work on Si-NW biosensors and nanotextured surfaces for surface enhanced Raman scattering and Raman spectroscopy and their integration with miniaturized lab-on-a-chip analytical systems

8371A-70, Session 4

Improving pain care in wounded soldiers

S. P. Cohen, The Johns Hopkins Hospital (United States); C. Kurihara, D. Jamison, S. Griffith, Walter Reed National Military Medical Ctr. (United States)

Non-battle injuries (NBI) represent the major cause of unit attrition since Vietnam. In the recent wars in Iraq and Afghanistan, the leading causes of medical evacuation are musculoskeletal injuries (24%), combat injuries (14%), neurological disorders (10%), psychiatric conditions (9%) and spinal pain (7%). Among non-combat-related injuries, the return-to-duty (RTD) rates for these conditions is significantly lower than for other causes of evacuation (musculoskeletal 13%, spine 14%, neurological 30%, psychiatric 9%).

There are two salient issues regarding pain care in service members (SM). The first revolves around how we can RTD as many SM as possible. The second challenge is to return injured SM's back to society in a condition as close as possible to their pre-deployment state. In this lecture, the prevalence rates, causes, and factors associated with RTD, will be discussed for a wide range of common pain conditions affecting SM, including spinal pain, headaches, and non-cardiac chest pain, as well as less common disorders such as post-amputation pain. Etiologies, mechanisms of pain, strategies for prevention, and treatment will be outlined.

8371A-72, Session 4

Decision support systems for robotic surgery and acute care

P. Kazanzides, Johns Hopkins Univ. (United States)

No abstract available

8371A-73, Session 4

A field-deployable device for the rapid detection of cyanide poisoning in whole blood

H. R. Boehringer, W. Tong, R. Chung, Diagnostic Consulting Network (United States); G. R. Boss, Univ. of California, San Diego (United States); B. J. O'Farrell, Diagnostic Consulting Network (United States)

Feasibility of a field-deployable device for the rapid and early diagnosis of cyanide poisoning in whole blood using the spectral shift of the vitamin B12 precursor Cobinamide upon binding with cyanide as an indicator is being assessed. Cyanide is an extremely potent and rapid acting poison with as little as 50 mg fatal to humans. Cyanide poisoning has been recognized as a threat from smoke inhalation and potentially through weapons of mass destruction. Currently, no portable rapid tests for the detection of cyanide in whole blood are available. Cobinamide has an extremely high affinity for cyanide and captures hemoglobin associated cyanide from red blood cells. Upon binding of cyanide, Cobinamide undergoes a spectral shift that can be measured with a spectrophotometer. We have combined the unique cyanide-binding properties of Cobinamide with blood separation technology, sample transport and a detection system, and are developing a rapid, field deployable, disposable device which will deliver an intuitive result to a first responder, allowing for rapid response to exposure events. Feasibility of the Cobinamide-Cyanide chemistry in a rapid test using a whole blood sample from a finger-stick has been demonstrated with an assay time from sample collection to a valid result of under 5 minutes. Data showing the efficacy of the diagnostic method and initial device design concepts will be shown.

8371A-07, Poster Session

MiniMAX: miniature, mobile, agile, x-ray system

S. Watson, S. Gonzales, G. A. Cunningham, Los Alamos National Lab. (United States)

We present a unique, lightweight, compact, low-cost, x-ray imager: MiniMAX (Miniature, Mobile, Agile, X-Ray System). This system, which exploits the best aspects of Computed Radiography (CR) and Digital Radiography (DR) technology, weighs less than 8lbs, fits into a 6" diameter x 16" long carbon-fiber tube, and is constructed almost entirely from off-the-shelf components including: a Leica M9 35mm camera; a 50mm, f0.95 Noctolux lens; and Fuji ST-55 phosphor screens. MiniMAX is suitable for use in weld inspection, archaeology, homeland security, and veterinary medicine. While quantum limited for MeV radiography, the quantum-efficiency is too low for routine medical use. Formats include: 4"x6", 8"x12", or 16"x24" that can be readily displayed on the camera back, using a pocket projector, or on a tablet computer. In contrast to a conventional, flying-spot scanner, MiniMAX records a photostimulated image from the entire phosphor at once using a bright, red LED flash, and then filtered through an extremely efficient (OD>10) dichoric filter. The red LED light is provided from a 1.5 lb, 350J, flash-circuit, specially tailored for hand-held operation. We present the system design and test results using a compact, Golden XRS-3, 350kV x-ray source.

8371A-49, Poster Session

Impedance spectroscopy for the detection of unknown toxins

B. Riggs, G. Plopper, T. Phamduy, Rensselaer Polytechnic Institute (United States); J. Paluh, Univ. at Albany (United States); D. T. Corr, D. B. Chrisey, Rensselaer Polytechnic Institute (United States)

Modern technologies allow for the manipulation of genetic material into user designed genomes. Although this is applied for health benefits through gene therapy, the same technology can be used to create custom biological toxins. Current detection methods rely on receptor-signal interactions that are highly sensitive, but only for a specific toxin. These structure-based biosensors can operate in real-time, however, they cannot detect custom toxins and, thus, do not provide proper protection. A function-based biosensor is necessary to achieve a real-time universal monitoring of a local environment for unknown health risks. Impedance spectroscopy is applied to a whole cell, function-based biosensor that allows for the detection of unknown toxins. Impedance spectroscopy applies a low current density AC signal, to a confluent mammalian epithelial cell monolayer (e.g., MDCK) grown on thin film interdigitated gold electrodes, over a range of frequencies (64 Hz-64 kHz) with a lock-in amplifier to measure the impedance in short (80 sec) intervals. Healthy monolayers form tight junctions between cells which act as a barrier to current flow, increasing the measured impedance. When exposed to cytoxins such as Bacillus anthracis lethal toxin or copper nanoparticles, changes in cell structure degrade tight junctions and decrease the measured impedance; all as a function of time. Impedance spectroscopy offers a real-time non-destructive method for detecting any substance that would elicit a cytotoxic response from mammalian cells and therefore can be used to detect both known and unknown threats in our environment.

8371A-50, Poster Session

GC-MS analysis of polybrominated diphenyl ethers in Lake Erie

M. C. Vagula, W. Tallmadge, M. Vartak, Gannon Univ. (United States)

With the strident mandates being imposed by environmental protection agency (EPA) on the use of certain organohalogens like polybrominated diphenyl ethers (PBDEs), there is a compelling reason to monitor their levels in all biota especially in the great lakes as these compounds are being added in most of the fire retardants. Lake Erie, one of the five Great Lakes of North America, biologically the most productive, the only drinking water source for 11 million, is fraught with environmental challenges.

By the year 2008, even though many congeners of PDBE got banned due to their adverse effects in experimental animals, their perpetuated traces in the living fauna and other permitted congeners like BDE-209 continue to perpetrate biological harm. PBDEs, being largely non-polar, chemically stable and extremely lipophilic resist degradation in the environment. On account of their high affinity for bioaccumulation, their levels seem to grow/persist unabated. This work presents the effects of PBDEs on glucose transport and sodium pump in the intestines of rodents. Also, it gives the most current update of the levels of the some commonly used PBDEs, namely, BDE-209, BDE-85, BDE-99 and BDE-47 in the water, sediments and biota of Lake Erie such as sucker fish, perch, and zebra mussel.

In our previous work, we only made a biochemical assay of their toxic effects. But in this research, more sophisticated and reliable methods employing gas chromatography- mass spectroscopy (GC-MS) technique are adopted along with computer based algorithms for accurate determination of PBDES and biomagnification thereof in the food-web.

8371A-51, Poster Session

Wireless data communication and power delivery through Faraday shielded metallic barriers for sealed sensing applications

J. D. Ashdown, Rensselaer Polytechnic Institute (United States)

A method for non-invasive two-way communication through a solid steel wall channel using ultrasonic techniques and power harvesting is presented. Two axially aligned piezoelectric transducers are mounted on opposing sides of a steel wall channel and a continuous wave (CW) carrier signal is applied to a transducer on the outside wall. A transducer on the inside wall modifies its acoustic impedance which, upon carrier reflection from the inside, results in an amplitude modulated (AM) signal on the carrier. The reflected AM signal is received by the outside transducer while it concurrently transmits into the wall. Custom circuitry has been developed for the inside and outside of the channel, and an ultrasonic through wall communication (UTWC) system is described which allows for successful communication of digital data through a steel wall. A method for two-way communication is also described which allows for the transmission of user specified commands from the outside to the inside of the channel to set the desired mode of system operation while allowing for the simultaneous transmission of sensor data from the inside to the outside of the same channel. Power harvesting techniques are employed which allow the inside electronics to operate without the need for a battery. It is shown that adequate power may be harvested to allow for the continuous operation of several inside sensors. Also, reliable communication of sensor data is shown at rates up to 20 kbps using 25.4 mm diameter 1 MHz transducers on steel wall thicknesses ranging from 57.15 - 304.8 mm.

8371A-52, Poster Session

Application of AVHHR based on the vegetation health indices for malaria vector assessment of Bangladesh

M. Z. Rahman, LaGuardia Community College (United States); L. Roytman, A. Rahman, The City College of New York (United States); A. H. Kadik, LaGuardia Community College (United States)

An epidemiological and ecological study has been conducted to determine the correlation between various environmental factors affecting malaria transmission and possibility for application remote sensing data as a proxy for monitoring the number of malaria cases. The area of study was Chittagong division in Bangladesh which has 60-80 percent of the entire country's malaria cases. Malaria statistics, satellite data and meteorological data were used in this study. Remote sensing data were presented by vegetation health indices (Vegetation Condition Index (VCI) Temperature Condition Index (TCI) and Vegetation Health Index (VHI)) derived from radiances, measured by the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA afternoon polar orbiting satellites. The investigation of factors contributing to malaria transmission was performed using correlation and regression analysis. The goal was to investigate if vegetation health indices can be used for detection, surveillance and numerical estimate of malaria development. Concerning the seasonal dynamics it should be emphasized that during cooler month (January-April) when mosquitoes are less active, the correlation is low. After April (week 16) when mosquito activity season starts, the correlation increases, fast reaching maximum (0.6 for TCI and -0.5 for VCI) around week 25 (end of June).

8371A-53, Poster Session

Quantum model of a biological attack using MAPLE

L. L. Alzate, Univ. EAFIT (Colombia)

A pathogen has the possibility to attack the human body causing diseases or epidemics depending of our defenses. Government and control health organizations have an especial interest in to know what is the probability of the human and a population to be attacked and infected by the pathogens and how it can be influenced by the virulence and concentration of the external agent or substance. In this way, physics has been involved in the solution of the problem giving to the global health institutions a guide to control the disease, by understanding the situation as a quantum phenomenon known as penetration of a potential barrier or as classical diffusion problem which involves the spatial and temporal variation of the concentration of the pathogen that causes the disease. The computations required to the solution of this problem are presented with MAPLE and is expected that this solutions have important implications to the global health care.

8371A-08, Session 5

Direct colorimetric detection of chemical warfare agents in both vapor and aerosol phases

M. Beshay, Intelligent Optical Systems, Inc. (United States)

No abstract available

8371A-37, Session 5

Remote detection of human toxicants in real-time using a human-optimized, bioluminescent bacterial luciferase gene cassette bioreporter

D. M. Close, The Univ. of Tennessee (United States) and 490 BioTech, Inc. (United States); S. A. Ripp, S. S. Patterson, G. S. Sayler, The Univ. of Tennessee (United States)

Traditionally, human toxicant bioavailability screening has been forced to proceed in either a high throughput fashion that uses prokaryotic or lower eukaryotic targets with minimal applicability to humans, or in a more expensive, lower throughput manner that uses fluorescent or bioluminescent human cells and can therefore directly provide human bioavailability data. While these efforts are often sufficient for basic scientific research, where rapid, specific target detection of human toxicants is not routinely required, they prevent the rapid and remote identification of potentially toxic chemicals required for modern biosecurity applications. Therefore, in an effort to merge the advantages of the high throughput, low cost toxicology screening regimens with the direct bioavailability assessment provided through the use of human cell lines, we have re-engineered and optimized the bioluminescent bacterial luciferase gene cassette to function autonomously (without exogenous reagent addition or excitation) within the human cellular environment. Expression of this optimized bioluminescent cassette provides the means for fully endogenous bioluminescent production from human cell lines, allowing continuous, real time monitoring for assessment of the bioavailability and toxicology of various compounds in an automated fashion. To access the functionality of this system, two sets of bioluminescent human kidney cell lines were developed. The first was programed to constitutively bioluminesce in the absence of toxins and suspend bioluminescent production upon toxicological challenge in order to mimic the non-specific detection of a toxic chemical release. The second was engineered to remain dark under ambient conditions and induce bioluminescence only upon detection of a specific toxic compound in order to demonstrate autonomous remote target identification. Continuously bioluminescent cells were capable of responding to μM concentrations of the known toxic aldehyde, n-decanal, and allowed for continuous monitoring of cellular health throughout the treatment process to determine the real-time level of human bioavailability. Specific toxicant-induced bioluminescence was generated through treatment with the antibiotic doxycycline and was detectable upon dosage at a 100 ng/ml concentration. These results demonstrate that by leveraging the autonomous bioluminescent nature of the bacterial luciferase gene cassette in human cell lines it will be possible to directly access human toxicant bioavailability in a low-cost, high throughput manner that can be easily adapted for fully automated, online remote monitoring.

8371A-40, Session 5

The global assimilation of information for action (GAIA) initiative: understanding the impact of climate change on national security and public health

S. B. Strong, L. J. Paxton, M. Nix, The Johns Hopkins Univ. Applied Physics Lab. (United States); W. H. Swartz, The Johns Hopkins Univ. Applied Physics Lab (United States); M. B. Weiss, R. Schaefer, The Johns Hopkins Univ. Applied Physics Lab. (United States)

The Global Assimilation of Information for Action (GAIA) is a new initiative at The Johns Hopkins University connecting decision-makers with the research community. GAIA's focus is on climate disruption and its effects on society and national security. The key to the GAIA approach is building connections through a series of topical cyber-enabled workshops. These workshops feature a structure that brings together people from a wide range of disciplines to exchange ideas and information, to assess and prioritize needs, and to develop approaches to addressing those needs. In addition to the workshops, GAIA has begun to design climate change and national security 'war game'-like scenarios, for a tailored, intensive analysis of complex societal and climate interactions.

The GAIA initiative, http://gaia.jhuapl.edu, includes a suite of visualization tools, documentation, analyses, and social networking capabilities. Here, we will discuss the GAIA collaboration and recent GAIA projects, in particular the development of climate change gaming scenarios and studies in public health, and how the GAIA project can aide in assessing national security and public health concerns. We will present key features of the GAIA visualization website, tools, and gaming development.

8371A-41, Session 5

Real-time global monitoring of volcanic ash using hosted sensors on the Iridium NEXT constellation

R. E. Erlandson, L. P. Dyrud, C. A. Hibbitts, C. K. Kumar, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Starting in 2015, Iridium expects to begin launching its next generation of communication satellites. The new spacecraft will replace Iridium's current constellation of 66 LEO satellites - the world's largest commercial satellite system. Known as Iridium NEXT, the new constellation has a built-in capability for hosting additional sensor payloads on the communication satellites which could be used for a wide range of Earth observation and government missions. The satellites are cross-linked resulting in a fully meshed network architecture provide real-time transmission of data from satellite sensors to end users on Earth. Moreover, the satellite data links can be used to relay data in real time. We propose integrating multi-spectral imaging sensors on each Iridium Next satellite in order to realize a global real time capability to detect volcanic ash. The motivation for this application is to provide real time alerts in support of FAA requirements for airline safety. This presentation will outline how this capability can be realized using low cost sensors to provide global real time warning. The discussion will include a discussion of the conceptual design of the sensor wave-bands needed to positively identify the location of ash clouds and ground processing needed to provide near real time alerts and warnings.

8371A-43, Session 5

Sensing and modeling urban boundary layer dynamics to better understand air quality health risks during heat waves

M. F. Arend, The City College of New York (United States); J. Pullen, Stevens Institute of Technology (United States); A. Jalloh, F. Moshary, The City College of New York (United States)

The challenge of understanding the dispersion properties of airborne toxins in highly populated regions is increasingly becoming a major concern as projections for global change are being realized. Whether the air quality health risks are a consequence of natural occurrences, anthropogenic developments or intentionally vicious attacks, detailed knowledge of the boundary layer dynamics is important to emergency responders in order to provide sufficient guidance. The sensitivity to boundary layer dynamics is amplified during events for which the evolution of stable urban boundary layers is less predictable (e.g. heat waves). The global trend towards urban coastal megacities puts an increasingly high importance for monitoring and modeling the meteorological conditions during heat waves. Understanding the interplay between dynamical forcings such as urban heat islands, sea breeze effects, etc. are needed for adequate representations of the transport and dispersion characteristics. A sensing network for studying these effects in the NY/NJ/greater NYC region includes a network of Doppler wind profilers (radar, sodar and lidar) in conjunction with high resolution surface observations. This sensing network is used to help validate the outputs of sub km meso-scale models in order to provide a more truthful depiction of atmospheric flows and the growth of internal boundary layers in urban regions. Particular examples in view of some recent heat waves will be given and the general outlook for future studies will be presented.

8371A-44, Session 5

Analytical determination and detection of odor signatures

R. M. Kramer, Air Force Research Lab. (United States)

While optimization of sensor devices will be critical for military utilization of odor signature profiling devices, overall knowledge of relevant volatile organic compounds that comprise these complex signatures is critical for device optimization. To that point, we are currently exploring the phenomenology of odor generation as a function of both genetics and environment. Utilizing the collaborative cross BXD animal model, we have begun to map the chromosomal areas responsible for odor emanations through quantitative trait loci mapping of recombinant inbred strains of these mice. In addition to understanding the genes that give rise to odor signatures, we have also identified odor profile changes that are induced by bacterial infection. Specific volatile compounds that arise due to infection have been discovered in response to pathogenic challenge by Bacillus anthracis, Yersinia pestis, and Francisella tularensis. Changes in the odorant profile from different mouse effluents due to pathogenic challenge have been observed to be both quantitative and qualitative in nature. In combination with chemokine/cytokine profiling in the BXD mouse models, susceptibility and resistance of particular strains, and high-throughput siRNA screening of human primary macrophage using the same bacterial infection models, we will utilize a systems biological approach to determine which odorants are most relevant and human-related. The identification of target odor biomarkers can be directly fed into to enhancing the selectivity for these targets and overall sensor device optimization.

8371A-46, Session 5

Analysis of carbon soil content by using tagged neutron activation

J. Obhodas, D. Sudac, Institut Ruder Bo?kovic (Croatia); V. Valkovic, A.C.T. d.o.o. (Croatia)

The forecast of massive and rapid global climate change due to the greenhouse gases appear every day more and more as a matter of fact. As a respond, the relatively new concept of global carbon market has been introduced, requiring among others, the accurate estimation and mapping of soil carbon content on large scales. Namely, relatively simple changes in cropping and tilling cycles can help capture more carbon dioxide from the atmosphere and store it into the soil. Carbon credit that can be traded in carbon markets is a property right which can be given if such activity can be equivalent to the amount usually expressed as a tone of the carbon dioxide removed from the atmosphere.

Since existing soil carbon measurements can not meet the needed criteria in terms of efficiency, method accuracy, verification and sampling error, we have developed a prototype for non-destructive, in-situ, accurate and cost-effectively measurement procedure of carbon in soil based on neutron activation analysis using 14 MeV tagged neutron beam. This technology can be used for carbon baseline assessment on regional scale and for monitoring of its surface and depth storage due to the changes in agricultural practices undertaken in order to mitigate global climate change.

8371A-47, Session 5

Modeling distributed feedback semiconductor lasers for carbon dioxide gas sensing

M. Shih, Univ. of Florida (United States)

Carbon-dioxide gas sensing has many important applications such as in fire detection, disaster response, military, surveillance, environmental monitoring, industry, and biomedicine. Gas sensing systems with semiconductor lasers have features such as small size, light weight, low cost, and low power-consumption. Semiconductor lasers with embedded corrugated metal gratings provide more precise and stable wavelength and enhance the sensing performance. This work demonstrates how parameters related to materials, structures, and optics affect the coupling coefficient, which is the key laser performance parameter. Numerical results with physical interpretation can provide more insights into the design and modeling of such lasers.

8371A-48, Session 5

Millimeter wave I-Q standoff biosensor

S. Liao, S. Bakhtiari, T. W. Elmer, Sr., A. P. C. Raptis, Argonne National Lab. (United States)

A continuous wave (CW) 94-GHz millimeter wave (mmW) biosensor has been developed for standoff biometric sensing applications. The sensor measures the demodulated in-phase (I) and quadrature-phase (Q) components of the received reflected mmW signal from a subject. Both amplitude and phase of the reflected signal are obtained from down-converted I and Q channels. The mmW sensor can faithfully monitor human vital signs (heartbeat and respiration) at relatively long standoff distances. A parameter-fitting method based on the Levenberg-Marquardt (LM) algorithm is used to extract both the respiration and the heartbeat signals. The approach allows extraction of information about amplitude and beat-to-beat rate of the respiration and the heartbeat. Experimental results collected from a subject was analyzed and compared to the signal obtained with a three-electrode ECG monitoring instrument.

8371A-65, Session 5

An overview of suite for automated global electronic biosurveillance (SAGES)

S. Lewis, Johns Hopkins Univ. Applied Physics Lab. (United States)

No abstract available

8371A-66, Session 5

Chemical and biological sensing needs for health effect studies

P. N. Breysse, Johns Hopkins Univ. Bloomberg School of Public Health (United States)

No abstract available

8371B-54, Session 6

A study on using middle-wave infrared images for face recognition

T. Bourlai, A. A. Ross, C. Chen, L. A. Hornak, West Virginia Univ. (United States)

The problem of face identification in the mid-wave infrared spectrum (MWIR) is studied in order to illustrate the advantages and limitations of intra-spectral (MWIR to MWIR) and cross-spectral (visible to MWIR) matching. The contributions of this work are two-fold. First, a database of 50 subjects is assembled and used to illustrate the challenges associated with the problem. Second, a set of experiments is performed in order to demonstrate the possibility of MWIR intra-spectral and cross-spectral matching. Experiments show that images captured in the MWIR wavelength band can be efficiently matched to MWIR images using both research and commercial software (originally not designed to address such a specific problem). These results are comparable to the baseline results, i.e., when comparing visible to visible face images. Experiments also show that cross-spectral matching (heterogeneous problem, where gallery and probe sets have face images acquired in different spectral bands) is a very challenging problem. Both independent and fused feature descriptors were tested, with fusion resulting in improved system performance. To the best of our knowledge, this is the first attempt in the open literature to investigate simultaneously the problems of intra-spectral (MWIR to MWIR) and cross-spectral (visible to MWIR) matching.

8371B-55, Session 6

Thermal to visible face recognition

J. Choi, Univ. of Maryland, College Park (United States); S. Hu, S. S. Young, U.S. Army Research Lab. (United States); L. S. Davis, Univ. of Maryland, College Park (United States)

In low light conditions, visible light face identification is infeasible due to the lack of illumination. For nighttime surveillance, thermal imaging is commonly used because of the intrinsic emissivity of thermal radiation from the human body. However, matching thermal images of faces acquired at nighttime to the predominantly visible light face imagery in existing government databases and watch lists is a challenging task. The difficulty arises from the significant difference between the face's thermal signature and its visible signature (i.e. the modality gap). To match the thermal face to the visible face acquired by the two different modalities, we applied face recognition algorithms that reduce the modality gap in each step of face identification, from low-level analysis to machine learning techniques. Specifically, partial least squares-discriminant analysis (PLS-DA) based approaches were used to correlate the thermal face signatures to the visible face signatures, yielding a thermal-to-visible face identification rate of 49.9%. While this work makes progress for thermal-to-visible face recognition, more efforts need to be devoted to solving this difficult task. Successful development of a thermal-to-visible face recognition system would significantly enhance the Nation's nighttime surveillance capabilities.

8371B-56, Session 6

Face recognition in the virtual world: recognizing avatar faces

R. V. Yampolskiy, Univ. of Louisville (United States); B. Klare, A. K. Jain, Michigan State Univ. (United States)

Criminal activity in virtual worlds is becoming a major problem for law enforcement agencies. In this paper a set of algorithms capable of verification and recognition of avatar faces with high degree of accuracy are described. Results of experiments aimed at within-virtual-world avatar authentication and inter-reality-based scenarios of tracking a person between real and virtual worlds are reported. We explored the use of (i) a Haar cascade trained on avatar faces, and (ii) the default frontal face Haar cascade. Geometric normalization was applied to reduce the effects of scale, rotation, and translations that occur within the detected face window. To compensate for changes in illumination, histogram equalization is performed to normalize the appearance. In order to match two avatar faces, we represent the face in a metric space by first computing a set of local feature descriptors across the face region. Two separate feature descriptors are used to describe (i) the structure of the face, and (ii) the appearance properties of the face. In the FERET-to-Avatar face dataset, where an avatar face was generated from every photo in the FERET database, a COTS FR algorithm achieved a near perfect 99.58% accuracy on 725 subjects. On a dataset of avatars from Second Life, the proposed avatar-to-avatar matching algorithm achieved average true accept rates of (i) 96.33% using manual eye detection, and (ii) 86.5% in a fully automated mode at a false accept rate of 1.0%.

8371B-57, Session 6

Dictionary-based methods for face and iris recognition

R. Chellappa, Univ. of Maryland, College Park (United States)

No abstract available

8371B-58, Session 7

Full-hand, 3D, non-contact scanner using sub-window-based, structured-light-illumination technique

V. Yalla, Flashscan3D LLC (United States); L. G. Hassebrook, Univ. of Kentucky (United States); R. Daley, C. Boles, M. Troy, Flashscan3D LLC (United States)

Fingerprint identification is a well-regarded and widely accepted modality in the field of biometrics for its high recognition rates. Legacy 2D contact based methods, though highly evolved in terms of technology suffer from certain drawbacks. Being contact based, there are many known issues which affect the recognition rates. Flashscan3D/University of Kentucky (UKY) developed state of the art 3D non-contact fingerprint scanners using different structured light illumination (SLI) techniques namely SLI single Point Of View (POV) and the SLI Sub-windowing techniques. Capturing the fingerprints by non-contact means in 3D gives much higher quality fingerprint data which ultimately improves matching rates over a traditional 2D approach. In this paper, we present a full hand 3D non-contact scanner using the SLI Sub-windowing technique. Sample fingerprint data and experimental results for fingerprint matching based on a sample 3D fingerprint test set are presented.

8371B-59, Session 7

Relaxing the constraints on image capture for iris recognition systems

P. A. Smith, TASC, Inc. (United States); J. M. Rickman, TASC, Inc (United States)

Iris recognition is considered to be one of the most accurate biometrics, but user inconvenience during the image acquisition phase has limited its

widespread use. Image capture is largely constrained to well-controlled situations, where subjects must remain relatively stationary or within a capture “volume” close to the camera. As a consequence, iris recognition systems have a reputation for being borderline intrusive, and less friendly for both subjects and operators. To support the development of a more natural and acceptable iris capture system, we have sought to develop a pre-processor driven imaging system that predicts a maximal opportunity window for iris capture for a subject engaged in natural motion based on predictive head and eye movement algorithms. This paper describes a first-generation prototype iris capture system that utilizes this approach. A wide field of view camera is used to track a person’s face and provide head pose data as input to the predictive algorithm. The algorithm is then used to direct a second narrow field of view camera to capture the iris image more reliably. This system serves as a platform for further development of head movement prediction algorithms used to enhance the probability of iris capture in moving or uncooperative subjects.

8371B-60, Session 7

Design and implementation of a contactless, multiple-hand-feature acquisition system

Q. Zhao, Harbin Institute of Technology (China) and The Hong Kong Polytechnic Univ. (Hong Kong, China); W. Bu, X. Wu, Harbin Institute of Technology (China); D. Zhang, The Hong Kong Polytechnic Univ. (Hong Kong, China)

In this work, we design an integrated contactless multiple hand feature acquisition system. The system can capture palmprint, palm vein, and palm dorsal vein images simultaneously. Moreover, the images are captured in a contactless manner, that is, users need not to touch any part of the device when capturing. Palmprint is imaged under visible illumination while palm vein and palm dorsal vein are imaged under near infrared (NIR) illumination. The capturing is controlled by computer and the whole process is less than 1 second, which is sufficient for online biometric systems. Based on this device, this paper also implements a contactless hand-based multimodal biometric system. Palmprint, palm vein, palm dorsal vein, finger vein, and hand geometry features are extracted from the captured images. After similarity measure, the matching scores are fused using weighted sum fusion rule. Experimental results show that although the verification accuracy of each uni-modality is not as high as that of state-of-the-art, the fusion result is superior to most of the existing hand-based biometric systems. This result indicates that the proposed device is competent in the application of contactless multimodal hand-based biometrics.

8371B-61, Session 8

3D face recognition opportunities and challenges

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No abstract available

8371B-62, Session 8

Gait identification from invisible shadows

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This paper introduces a novel system for person identification from shadow images of walking person projected by invisible lights, and a shadow database of walking people. In general the correct classification rate of person identification is better when multiple cameras from different viewpoints are used, but most of conventional methods have used one camera, because of (i) easy installation in real environments, since there is no need to synchronize cameras, (ii) reduction of calculation costs. In the proposed system, we obtain the advantages of multiple viewpoints but with a single camera. More specific, we install multiple infrared lights to project shadows of a subject on the ground and a camera with an infrared transmitting filter to the ceiling inside of a building. Shadow areas, which are projections of one’s body on the ground by multiple lights, can be considered as body areas captured from different viewpoints, so the proposed system enables to capture multiple body areas from only one camera. We collect a shadow database consisting of 28 people with this system, and we extract features from shadow areas by affine moment invariants, followed by identification of the subject. Experiments using the gait database show the effectiveness of the proposed method.

8371B-63, Session 8

Biometrics via IR spectroscopy of the epidermis: potential and difficulties

D. M. Mackie, U.S. Army Research Lab. (United States)

We discuss the potential and difficulties of using infrared (IR) spectroscopy of the human epidermis as a biometric. We present preliminary data on the fingerpads of 9 individuals demonstrating the potential for uniqueness and stability. We also present data on the challenges presented by complications such as sebum changes, intra-individual location variability, and skin care products.

8371B-64, Session 8

Fusion of footsteps and face biometrics on an unsupervised and uncontrolled environment

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Unobtrusive biometric systems are receiving recently great attention from the research community due to the high degree of acceptability from the users in different applications. Footsteps and face are two good examples of unobtrusive biometrics, which could be fused. Footstep recognition is a relatively new biometric, which aims to discriminate persons using walking characteristics extracted from floor-based sensors. On the other hand, face is a modality with better individual performance compared to footsteps, but it is strongly affected by external factors such as illumination, pose, subject-to-camera distance or appearance.

This paper is focused on the fusion of footsteps and face on an unsupervised and uncontrolled environment, where a person walks freely over an area without having to interact with any device. Some previous related works have carried out the fusion between face and gait achieving very good recognition results due mainly to the uncorrelation of both biometrics. This is a similar case to ours, although footsteps is a more controlled mode compared to gait, but signals are more robust to environmental conditions, with minimal external noise sources to corrupt the signals.

The fusion of footsteps and face is carried out at the score-level with different score normalization techniques in order to make comparable the scores from the two systems. Two different fusion architectures have been considered, an ideal case and a more realistic case with an adaptive fusion. Also, two different applications have been simulated: smart homes (small group of users with a large set of training data) and security access (larger group of users with a small set of training data), obtaining best results of 0.9% and 5.8% EER for the fusion of both biometrics for each application respectively.

The paper is organized as follows. The main interests of the research are introduced in Section 1. Section 2 describes the footstep signals and the footstep recognition system. Section 3 presents the face signals and the face recognition system. Section 4 describes the experimental protocol followed for the fusion, Section 5 presents the experimental results; and finally conclusions are drawn in Section 6.

8371B-65, Session 9

Matching challenging ocular images

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No abstract available

8371B-66, Session 9

A study on quality adjusted impact of time lapse on iris recognition

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In order to investigate changes in iris recognition performance due to the elapsed time between probe and gallery iris images, our study analyzes 7,628 iris images from 46 subjects with an average of ten visits over two years from a legacy database at Clarkson University, resulting in 67932 matched pairs of images. In this study we measure the quality of each iris image in terms of contrast, illumination, noise and blur and incorporate these quality metrics into two iris recognition algorithms (VeriEye and Masek) for testing the variability of the recognition system. Regression models were built with and without quality factors to evaluate the degradation of recognition performance for elapsed time. In both cases, time lapses showed high significance in explanation of the match scores (p-value < 0.0001). Performance for VeriEye decreased from 97.5% TAR at 0% FAR for time lapse less than 180 days compared to 93.3% TAR at 0% FAR for time intervals greater than 720 days. Similar decrements were seen for the implemented Masek algorithm. Our experimental results show the decrease in iris recognition performance with increased elapsed time on this dataset. While we are controlling for quality in the analysis, it is possible that the quality metrics we have utilized are not adequately accounting for poor-quality images, as well as other factors such as changes in data collection procedures.

8371B-67, Session 9

CUE: counterfeit-resistant usable eye-based authentication via oculomotor plant characteristics and complex eye movement patterns

O. V. Komogortsev, A. Karpov, C. Holland, Texas State Univ. San Marcos (United States)

The spread of computers in human society introduces a necessity for usable and counterfeit-resistant authentication methods to provide secure access at public terminals to personal resources such as bank accounts, e-mail, social media, and various other protected resources. Most existing authentication methods employed today at public places require remembering a pass phrase, are prone to shoulder-surfing and involve authentication techniques that can be counterfeited by replicating/removing parts of the human body and/or guessing an authentication token by knowing some information about a user.
This paper describes preliminary work toward a counterfeit-resistant usable eye-based (CUE) authentication method that does not require any passwords therefore improving the memorability aspect of the authentication system. CUE aims to provide high resistance to spoofing and shoulder surfing by employing combined biometric capabilities of two traits 1) internal non-visible anatomical structure of an eye called oculomotor plant characteristics (OPC) and 2) brain visual attention strategies represented by the Complex Eye Movement patterns (CEM). Both OPC and CEM are extracted from the eye movement signal captured by a special device called an eye tracker. Collected data indicates that fusion of the OPC and CEM traits provides substantial reduction of the authentication errors when compared to the results obtained by each modality alone.

8371B-68, Session 9

Multiple hand vein recognition based on orientation of LBP

W. Bu, X. Wu, E. Gao, K. Wang, Harbin Institute of Technology (China)

As vein patterns, which rely on the interior biological information of the body, cannot be easily damaged or faked, vein recognition is becoming an effective method for personal recognition. This paper proposes a novel approach for multiple hand vein recognition based on orientation of local binary pattern (LBP). The vein images used in this paper include palm vein, dorsal vein and three finger veins (index, middle, ring finger). In this approach, the vein images are firstly preprocessed to get regions of interest (ROIs). Then these ROIs are enhanced by using a bank of 2D Gaussian match filters. Thirdly, the orientations of the veins are computed by applying LBP operator. After that, the orientations of LBP of different vein images are matched respectively. Finally, the matching distances of the different vein images are fused to make a final distance for decision by making use of support vector machine (SVM). The experimental results on a large database demonstrate the effective of the proposed approach.

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8372-01, Session 1

Modular multichannel imaging system for littoral observation and target detection

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A series of UAS-capable multi-channel imagers have been developed under SBIR funding through NAVAIR. This paper discusses the application of these sensors to littoral observations/reconnaissance and littoral subsurface target detection. These imagers consist of a turreted multi-camera sensor head and an associated data acquisition and processing unit. A description of the sensor head, tailored for littoral operations, and the acquisition unit are given. Data collected off the coast of Alabama in the summer of 2011 is used to develop the real-time target detection algorithms and to demonstrate an environmental reconnaissance capability.

The sensor systems are the EYE5 series of sensors developed by Advanced Coherent Technologies under SBIR funding. They integrate multiple 1.4 megapixel 12 bit CCDs into a commercial CloudCap TASE 300 turret. Each CCD is coupled with filters and optics appropriate for specific operations. The acquisition and processing system is based on the Vision4ce CPU/GPU ruggedized computer system.

8372-02, Session 1

Compact optical system for imaging underwater and through the air/sea interface

D. M. Alley, L. J. Mullen, A. Laux, Naval Air Systems Command (United States); W. E. McBride III, U.S. Naval Research Lab. (United States)

Typical line-of-sight (LOS) optical imaging systems include a laser source and receiver that are co-located on the same platform. The performance of such systems is deteriorated in turbid ocean water due to the large amount of light that is scattered on the path to and from an object of interest. Imagery collected with the LOS through the air/sea interface is also distorted due to wave focusing/defocusing effects. The approach of this project is to investigate an alternate, non-line-of-sight (NLOS) approach that offers some advantages over these traditional LOS imaging techniques. In this NLOS system the laser and receiver are located on separate platforms with the laser located closer to the object of interest. As the laser sequentially scans the underwater object, a time-varying intensity signal corresponding to reflectivity changes in the object is detected by the distant receiver, which is not adversely affected by scattering. A modulated laser illuminator is used to communicate information about the scan to the distant receiver so it can recreate the image with the collected scattered light. This NLOS configuration also enables one to view an underwater target through the air-sea interface (transmitter below the surface and receiver above the surface) without the distortions experienced with the LOS sensor. In this paper, we will review the results of recent laboratory water tank experiments where an underwater object was imaged with the receiver both below and above the sea surface. We will also report on results from experiments to be conducted in local in-situ environments. These results will be compared to a preliminary model.

8372-03, Session 1

Scattered photons as useable signal for underwater imaging

W. E. McBride III, U.S. Naval Research Lab. (United States)

The orthodox approach to designing an underwater imaging system with artificial illumination has been to consider only the unscattered target photons as the useable signal while looking at scattered photons as a nuisance to be mitigated. An unconventional system was originally developed at the Visibility Laboratory in the early 1970's that uses both scattered and unscattered photons as useable signal for imaging, thereby dramatically improving performance in turbid waters. In this paper, a real-time interactive simulation of TVI's expected performance is presented and model predictions are compared with experimental imagery acquired when laser and receiver are both located underwater.

8372-04, Session 1

In-situ digital holography and adaptive sampling enable the study of the interactions of particles, organisms and bubbles within their natural environment

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The link between suspended particle fields, particle dynamics and bulk optical properties in natural waters is poorly known because adequate technology is lacking to fully characterize critical parameters and interactions (especially for ephemeral bubbles and aggregates). Holography provides non-intrusive, high-resolution 3-D imaging of particles (including bubbles) in their natural environment, at a resolution and sample volume no other instrument can currently achieve. As part of a NOPP project (HOLOCAM) to commercialize an in-situ digital holographic microscope (DHM), field data with a prototype in-situ DHM (the 'Holosub') were collected in East Sound, WA; an environment that typically has both zooplankton and phytoplankton thin layers, and notable particle dynamics. The Holosub was deployed in two configurations: free-drifting mode for vertical profiling, and towed mode. In free-drifting mode, vertical profiles of shear strain and dissipation rates, undisturbed size and spatial distributions of particles and organisms in thin layers, and demonstrated orientation of diatom chains were recorded using the holographic images. Hydrographic and optical data, as well as discrete water samples to identify phytoplankton species were concurrently collected. In towed mode, the size and spatial distributions of bubbles just below the surface were recorded to characterize the dissipation of a wake generated by another ship, and compared to optical and acoustic scattering data recorded simultaneously. These analyses are ongoing. Results from this study and a project overview will be presented.

8372-05, Session 1

Bahamas optical turbulence exercise (BOTEX)

W. W. Hou, E. Jorosz, S. Woods, U.S. Naval Research Lab. (United States)

Bahamas Optical Turbulence Exercise (BOTEX) was conducted in the coastal waters of Florida and Bahamas, from June 30 to July 12, 2011 onboard RV FG Walton Smith. The primary objective of BOTEX is to obtain field measurements of optical turbulence structures and to investigate turbulence impacts on underwater imaging and beam propagation. In order to successfully image over optical turbulence structures in the water, and examine their impacts on optical transmission, a high speed camera and target(s) (both active or passive) were mounted on a rigid frames to form iMAST (image measurement assembly for subsurface turbulence). To investigate the impacts on active imaging system such as laser line scan (LLS), Turbulence Research for Undersea Sensing Structure (TRUSS) was designed and implemented by HBOI. The experiments were designed to determine the resolution limit of LLS systems due to beam wander at the target due to turbulences. The impact of natural turbulent structures on Lidar backscatter waveforms were also examined, where the telescopic receiver and short pulse transmitter were co-located on a vertical profiler. Data from four stations were collected, covering different types of optical and physical conditions. Impacts from optical turbulence were observed under both strong and weak physical structures. Turbulence measurements were made by both Vertical Microstructure Profiler (VMP) and a 3D acoustical Doppler velocimeter (Vector) with fast conductivity and temperature (CT) probes in close proximity in the field, and subsequently with Vector/CT mounted on the iMAST during moored deployments. Turbulence kinetic energy dissipation rate and temperature dissipation rates were calculated from both setups, in order to characterize the physical environments and their impacts. Initial results confirm our hypothesis of turbulence impacts on optical transmissions, while also suggest more research are needed to better quantify and mitigate such effects, especially for Navy's next generation EO systems including active imaging, lidar and optical communications.

8372-06, Session 1

Inital observations of turbulence and polarization from the Bahamas Optical Turbulence Exercise

S. Woods, U.S. Naval Research Lab. (United States); A. K. Vuorenkoski, Florida Atlantic Univ. (United States); W. W. Hou, E. Jarosz, U.S. Naval Research Lab. (United States)

In the marine environment, near-forward scattering of light can be strongly influenced by turbulent flow in the water column. Turbulent inhomogeneities of the flow are associated with fluctuations in temperature and salinity. Variations in these passive scalars alter the water density, inducing variations in the refractive index. These fluctuations in the refractive index then refract the light as it passes through the turbulent layer, effectively inducing multiple forward scattering in the light beam. For polarimetric applications, this turbulent scattering can lower the degree of polarization of the optical beam. As part of the Bahamas Optical Turbulence Exercise (BOTEX), July 2011, coincident measurements were made of the turbulence strength and the optical depolarization over a 10 cm path length near the ocean mixed layer. The turbulent strength is characterized by the turbulent kinetic energy (TKED) and thermal (TD) dissipation rates. The TKED rate, ε, determines the size of the smallest structure within the flow, and may be determined by the spatial gradients of the velocity field. The TD rate, χ, describes the size of thermal variations across the smallest structure of the flow, and may thus be determined by the spatial gradient of temperature variations. We present preliminary observations of the coincident turbulence characterization and degree of polarization measurements during BOTEX.

8372-07, Session 1

The spatial and temporal structure of thermal fluctuations associated with a vertical turbulent jet impinging a water surface: laboratory experiments and field observations

K. P. Judd, I. Savelyev, G. B. Smith, G. O. Marmorino, U.S. Naval Research Lab. (United States)

Infrared imaging, in both laboratory and field settings, has become a vital tool in diagnosing near-surface thermal-hydrodynamic phenomena such as convective cells, accumulation of surfactant, and coherent turbulent structures. In this presentation, we initially focus on a laboratory scale (0.01-1m) subsurface vertical turbulent water jet that serves as a canonical flow. The jet has a slightly elevated temperature thus the warmer fluid serves as a passive marker. Infrared image sequences of the surface thermal field were collected for various water jet flow rates and for both "clean" and surfactant-contaminated surface conditions. Turbulent characteristics of the near-surface flow field were measured by means of Digital Particle Image Velocimetry (DPIV), and these are used to examine the statistical nature of the coupled thermal-hydrodynamic field. An analog of the laboratory jet is the discharge of power-plant cooling water through a vertical pipe on the ocean floor. High-resolution airborne infrared imagery has recently been acquired of such a discharge (from the Huntington Beach Generating Station, CA), and these data are compared with the laboratory results in an attempt to understand striking spatial patterns discovered on the ocean surface.

8372-08, Session 1

An optically remote powered subsea video monitoring system

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The drive for Ocean pollution prevention requires a significant increase in the extent and type of monitoring of subsea hydrocarbon production equipment. Sensors, instrumentation, control electronics, data logging and transmission units comprising such monitoring systems will all require to be powered. Conventionally electrical powering is supplied by standard subsea electrical cabling.

The ability to visualise the assets being monitored and any changes or faults in the equipment is advantageous to an overall monitoring system. However the effective use of video cameras, particularly if the transmission of real time high resolution video is desired, requires a high data rate and low loss communication capability. This can be challenging for heavy and costly electrical cables over extended distances. For this reason optical fibre is often adopted as the communication channel. Using optical fibre cables for both communications and power delivery can also reduce the cost of cabling.

In this paper we report a prototype optically remote powered subsea video monitoring system that provides an alternative approach to powering subsea video cameras. The source power is transmitted to the subsea module through optical fibre with an optical-to-electrical converter located in the module. To facilitate intelligent power management in the subsea module, a supercapacitor based intermediate energy storage and an automatic control circuit are installed. The subsea module is also encapsulated for subsea testing. Feasibility of the system will be demonstrated. This will include energy charging and camera operation times. Subsea trials for powering the module at varying distances will also be reported. Finally other potential subsea applications of the remote powering systems will be discussed.

8372-09, Session 1

Integration of SAR and AIS for ship detection and identification

C. Yang, T. Kim, E. K. Oh, Korea Ocean Research & Development Institute (Korea, Republic of)

Integration of Synthetic Aperture Radar (SAR) and Automatic Identification System (AIS) are the important issues for monitoring and controlling the ships in ocean. The overview of an integrated technique will be presented in this paper which describes the matching of SAR-AIS contacts to carry the design concept. After being detected in SAR images, the ships position will be correlated with AIS in order to identify the ship's identity over an image. Time matching between image acquisition as well as the AIS provides the closest time signal report in order to estimate dead-reckoning(DR) of the ships. Azimuth shift compensation has also been estimated to compensate the position to

the actual position. After being compensated, DR located ship will search the nearest SAR derived ship target around a certain region of interest with matching of ship's dimension, speed. At Final, the DR based ship's hull acquires the nearest distance ship target with well-matched hull placed over compensated SAR-derived ship target position in order to present integrated system design result. Thereby this service may acts as an early warning system to help security authority to identify friend and foe vessel presents in ocean.

8372-10, Session 2

Development of a fluorescence polarization submersible instrument for the detection of submerged heavy oil spill

J. Bello, A. G. Smirnov, P. Toomey, EIC Labs., Inc. (United States)

Spills of Group V heavy oils are a concern because once spilled heavy oils will immediately sink to the bottom and can harm wetlands, beaches, and marine life. Recently, we developed a new tool-fluorescence polarization (FP)- for locating heavy oil deposits. The method relies on the observation that heavy, viscous oil fractions exhibit polarized fluorescence while the ubiquitous fluorescence background characteristic of chlorophyll and humic compounds do not. The basic FP measurement entails exciting the fluorophore with polarized light and observing the intensities of the emission polarized perpendicular and parallel to it. Heavy, tarry oils containing higher molecular weight polynuclear aromatic hydrocarbons fractions exhibit strong FP. The development of a remotely operated, submersible FP instrument will be presented, as well as testing results of the instrument in a simulated spill set up by the US Coast Guard at the National Oil Spill Response Research & Renewable Energy Test Facility (OHMSETT). The FP instrument utilizes a laser (532 nm) to excite the oil matrix. A small refracting telescope with variable focus is employed as the front optics and used to focus the laser beam and to collect the polarized fluorescence from the sample at a standoff distance. An embedded computer resides inside and controls the various operations such as autofocusing of the telescope and data acquisition. The embedded computer also allows autonomous or remotely controlled operation. Phase sensitive detection technique is also employed to remove the effect of solar background allowing the use of the instrument during daylight hours.

8372-11, Session 2

Introduction of oil spill monitoring and response support system using satellite remote sensing

T. Kim, E. K. Oh, C. Yang, Korea Ocean Research & Development Institute (Korea, Republic of)

In the case of oil spill accident at sea, cause the bad effect onto the around sea area such as ocean pollution, property loss etc. If accident area is close to land, it is diffuse at coastal ocean area by tidal current and wind because oil spill on the top of the oceanic surface has layer due to lower mass density than ocean waters. And it cause additional damage to both offshore structures and ocean ecosystem. Therefore, quick making response strategies must be need to prevent additional damage and that is possible by developing system with offered integrated information, such as accident position, oil spill area, movement direction and combating resources.

This abstract is explains the GIS system for visualization of oil spill monitoring and predicting movement. The purpose of this system is to easily understand of integrated oil spill information by plot on a program base on electronic navigation chart. Oil spill analysis tool is offer input data such as outline coordinates of detected oil spill and the information about the source satellite image, the oil spill and any possible sources in SAR image. These input data are covert into appropriate format to plot on a program base on electronic navigation chart. Converted file formats are expressed as follows. 1. Satellite image after carry out geometric correction and resizing is convert into BMP,BMW file format. 2. Detected oil spill is convert into shapefile(.shp, .shx, .dbf) format of polygon type using outline coordinates. 3. Oil Report and combating Resources are convert into BMP,BMW file format of table type.

Close to land, the strength and direction of any current and wind are cause movement of detected oil spill. This system is designed to plot oil spill on specific time and predicting oil spill trajectories with current and wind. Each data is extracted by computer modeling, the grid spacing is 4km and interval of time is 12hour. Oil spill movement must be superimposed both 100% of the current strength and 3% of the wind speed.

8372-12, Session 2

Fingerprinting of crude oil using fluorescence spectroscopy

A. S. Holmes-Smith, M. Uttamlal, D. M. Hepburn, Glasgow Caledonian Univ. (United Kingdom); A. Graham, D. Faichnie, FMC Technologies Ltd. (United Kingdom)

Crude oil is a complex mixture of hydrocarbons (e.g. paraffins, aromatics, napthenes), sulphur compounds (e.g. sulphur, sulphides), amines, metals (e.g. Ni, Fe) and salts (e.g. NaCl, sand). Quantitative chemical analysis of such combinations is difficult and requires partial or complete separation of the components, challenging outside of the laboratory. Qualitative chemical analysis of oil is simpler using techniques such fluorescence spectroscopy. In this paper we will present fluorescence (spectra and lifetime) data for crude oil samples of varying (specific) API gravity and show how qualitative chemical information can be extracted from the spectra. This will include data obtained using synchronous scanning fluorescence spectrometry and time resolved emission spectroscopy (TRES) and demonstrate the ability of utilising these methods to obtain better qualitative chemical information and hence the ability to "fingerprint" crude oil.

8372-13, Session 3

Application of laser-source based calibration for VIIRS for ultra-high accuracy radiometric calibration and some considerations on uses of those calibrations for ocean color studies

B. Guenther, Univ. of Maryland, Baltimore County (United States)

The Visible/Infrared Imaging Sensor Suite (VIIRS) is operating on orbit now on the NPOESS Preparatory Project Observatory. Numerous components of the prelaunch test program for bands centered below 1 μm were dictated by the performance requirements for ocean color retrievals. Several of these characterizations evolved from its legacy sensor Moderate Resolution Imaging Spectrometer (MODIS). Addition of a laser-based test source (Traveling SIRCUS - Speatral Radiance and Iradiance responsivity Calibration using Uniform Sources) provided superior characterization for spectral testing and for radiometric response knowledge. Polarization testing upgrades for VIIRS compared to MODIS have been accomplished as well. Analysis suggests that band to band radiometric uncertainty is well below 0.5% for the OC bands, and spectral registration is better than 0.1 nm in band center. Results presented show that error of 1 nm in band center may introduce as 10% biases in nLw, or greater, in ocean scenes.

8372-14, Session 3

Early results from NPP VIIRS on-orbit calibration

X. Xiong, NASA Goddard Space Flight Ctr. (United States); C. Cao, National Oceanic and Atmospheric Administration (United States); F. DeLuccia, The Aerospace Corp. (United States); B. Guenther, Univ. of Maryland, Baltimore County (United States); J. Butler, NASA Goddard Space Flight Ctr. (United States)

The first Visible-Infrared Imaging Radiometer Suite (VIIRS) sensor was launched onboard the NASA's NPP spacecraft on October 28, 2011 from the Vandenberg Air Force Base (VAFB). The VIIRS makes observations in 22 spectral bands, covering wavelengths from 0.41 to 12.5 microns, and produces 22 Environmental Data Records (EDRs) from its calibrated and geolocated Sensor Data Records (SDRs). To maintain its calibration and data product quality throughout its entire mission, the VIIRS was built with a set of on-board calibrators (OBC), including a solar diffuser (SD), a solar diffuser stability monitor (SDSM), and a SD attenuation screen system for the reflective solar bands (RSB) calibration and a blackbody (BB) for the thermal emissive bands (TEB) calibration. This paper provides an overview of VIIRS on-orbit calibration activities, methodologies, and designed OBC functions. It presents an early assessment of sensor on-orbit calibration performance based on the efforts from the government-led SDR team. Key sensor performance parameters determined during its initial Intensive Calibration and Validation (ICV) period, such as detector signal-to-noisy ratios (SNR) or noise equivalent temperature difference (NEdT), radiometric gains, and dynamic range, are reported and compared with that derived from pre-launch calibration and characterization. Current issues, identified and resolved, and future calibration efforts, including the Long-Term Monitoring (LTM) activities and lunar calibration strategies, are also discussed.

8372-15, Session 3

Validation of ocean color on VIIRS

R. Arnone, U.S. Naval Research Lab. (United States)

No abstract available

8372-16, Session 3

Initial results of NPP VIIRS SST processing at NAVOCEANO

B. Mckenzie, U.S. Navy (United States); D. A. May, U.S. Naval Research Lab. (United States); K. D. Willis, Naval Oceanographic Office (United States); J. P. Cayula, QinetiQ North America (United States)

The NPOESS Preparatory Project (NPP) satellite was placed in orbit October 28, 2011 and began providing advanced imaging and radiometric data from the Visible Infrared Imager Radiometer Suite (VIIRS) in December 2011. The Naval Oceanographic Office (NAVOCEANO) is processing the VIIRS data in the generation of sea surface temperature retrievals for ingest by Navy meteorological and ocean analyses and models. This new sensor has an increased number of channels, higher resolution, and larger volume than previous operational polar orbiting environmental satellites. In order to be ready to process this new data, a proxy datastream was generated by the Government Resource for Algorithm Verification, Independent Testing, and Evaluation (GRAVITE) from Moderate-resolution Imaging Spectroradiometer (MODIS) data and provided in near real-time. This allowed for NAVOCEANO to write software to ingest, process, and deliver SST products before the actual data began flowing. A discussion of these preparatory activities and the initial results of processing VIIRS SSTs will be presented, including global drifting buoy matchup statistics.

8372-17, Session 3

Monitoring of IR clear-sky radiances over oceans for SST (MICROS): readiness for NPP/VIIRS

X. Liang, NOAA/NESDIS (United States) and Cooperative Institute for Research in the Atmosphere (United States); A. Ignatov, NOAA/NESDIS (United States); K. Saha, NOAA/NESDIS (United States) and Cooperative Institute for Research in the Atmosphere (United States)

Monitoring of IR Clear-Sky Radiances over Oceans for SST (MICROS) is a Web-based tool to monitor model minus observation (M-O) biases in clear-sky brightness temperatures (BTs) and sea surface temperatures (SSTs) produced by the Advanced Clear-Sky Processor for Oceans (ACSPO). The fast Community Radiative Transfer Model (CRTM) is employed to simulate clear-sky BTs, using Reynolds SST and NCEP/GFS atmospheric profiles as inputs. Simulated BTs are used in ACSPO for improved cloud screening, physical SST inversions, and monitoring and validating satellite BTs and CRTM. The key MICROS objectives are to fully understand and reconcile the measured and simulated BTs, and minimize cross-platform biases through improvements to ACSPO algorithms, CRTM and its inputs, satellite radiances, and skin-bulk and diurnal SST modeling. Until recently, MICROS monitored M-O biases in three AVHRR bands centered at 3.7, 11, and 12 μm for five satellites, NOAA-16, -17, 18, -19 and MetOp-A. In preparation for launch of NPP/VIIRS in October 2011 and MetOp-B in April 2012, MICROS functionality is being extended to additionally monitor clear-sky ocean radiances in AVHRR-like bands from two MODIS instruments onboard Terra and Aqua, and VIIRS proxy data generated from Aqua/MODIS. NPP/VIIRS and MetOp-B/AVHRR clear-sky radiances will be added in MICROS once these satellites are launched and sensor data become available. In this presentation, preliminary results of AVHRR-MODIS-VIIRS radiance consistency are discussed.

8372-18, Session 3

Automated ocean color product validation for the Southern California Bight

C. O. Davis, N. Tufillaro, Oregon State Univ. (United States); R. Arnone, U.S. Naval Research Lab. (United States); B. Jones, The Univ. of Southern California (United States)

Automated match ups allow us to maintain and improve the products of current satellites (MODIS, MERIS), and new platforms (VIIRS). As part of the VIIRS mission preparation, we have created a web based automated match up tool that provides access to searchable fields for date, site, and products, and creates matchups between satellites (MODIS, MERIS, VIIRS), and in-situ measurements (HyperPRO and SeaPRISMs). The back end of the system is a 'mySQL' database, and the front end is a `php' web portal with pull down menus for searchable fields. Based on selections, graphics are generated showing matchups and statistics, and ascii files are created for downloads for the matchup data. Examples are shown for matching the satellite data with the data from Platform Eureka SeaPRSIM off L A Harbor in the Southern California bight.

8372-19, Session 3

A methodology for calibration of hyperspectral and multispectral satellite data in coastal areas

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A methodology to investigate suitable in situ sampling locations to calibrate and validate (Cal/Val) remote sensing is presented. The approach uses satellite time-series acquisitions to build a covariance matrix that encodes the spatial-temporal variability of the area of interest. The covariance matrix is then employed in a Bayesian framework to merge satellite and in situ data providing a product with lower uncertainty. The best in situ location is retrieved using a design principle that looks for minimizing the variance of the merged product. Specifically, it is determined the location(s) where in situ sampling provides the greatest improvement when merged with satellite remote sensing data (lowest uncertainties).

The proposed method was tested using Sea Surface Temperature and Ocean Color products (from AVHRR and MODIS sensors) and it will support the approaching launch of VIIRS (27 October 2011). In situ measurements are obtained from mooring (AErosol RObotic NETwork-AERONET and Marine Optical Buoy-MOBY) or from autonomous vehicle (Gliders).

8372-20, Session 4

Selecting a first-guess SST as input to ACSPO

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Advanced Clear-Sky Processor for Oceans (ACSPO) is the newer NESDIS clear-sky radiance and sea surface temperature (SST) retrieval system. It provides clear-sky top of the atmosphere (TOA) observed brightness temperatures (BT) in AVHRR Ch3B(3.7), Ch4(11), and Ch5(12µm), along with their simulated values employing the fast community radiative transfer model (CRTM), using first-guess SST (Reynolds) and upper air (NCEP GFS) fields as inputs. Simulated first-guess BTs are used for accurate ACSPO clear-sky mask, physical SST retrievals, monitoring sensor performance, and CRTM validation. Model minus observation (M-O) biases are continuously monitored using the near-real time online-tool, Monitoring of IR Clear-sky radiances over Oceans for SST (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/). This study tests several other Level 4 (L4) SST products as potential first-guess SSTs in ACSPO. Eleven different L4 SST fields have been evaluated, which are compared with each other and with quality controlled in situ data in L4-SST Quality Monitor (SQUAM; http://www.star.nesdis.noaa.gov/sod/sst/squam/L4/). Our analyses use a different approach, based on comparisons with the ACSPO L2 SST product as a “transfer standard”. Three metrics are introduced and employed in the L4-comparisons: the global spatial variance of the M-O biases; and their temporal stability along with the corresponding double-differences. It is generally observed that the Group for High-Resolution SST (GHRSST) Multi-Product Ensemble (GMPE), Canadian Meteorological Centre (CMC 0.2º) and UKMO OSTIA provide an improved combination of metrics and thus serve as a more consistent first-guess SST field. Using these first-guess SSTs also slightly improves water vapor and angular dependencies of the M-O BT biases.

8372-21, Session 4

Evaluation of atmospheric correction procedures for ocean color data processing using hyper- and multi-spectral radiometric measurements from the Long Island Sound Coastal Observatory

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In Ocean Color (OC) data processing one of the most critical steps is the atmospheric correction procedure used to separate the water leaving radiance, which contains information on water constituents, from the total radiance measured by space borne sensors, which contains atmospheric contributions. To ensure reliability of retrieved water leaving radiance values, and OC information derived from them, the quality of the atmospheric correction procedures applied needs to be assessed and validated. In this regard, the Long Island Sound Coastal Observatory (LISCO), jointly established by the City College of New York and the Naval Research Laboratory is becoming one of the key elements for OC sensors validation efforts, in part because of its capabilities for co-located hyper and multi-spectral measurements using HyperSAS and SeaPRISM radiometers respectively, with the latter part of NASA AERONET - OC network. Furthermore, as is shown here, merging of SeaPRISM and HyperSAS data from the LISCO site significantly improves the overall retrieved data quality, and that this makes the use of these datasets particularly well suited for making assessments of the efficacy of different atmospheric correction procedures. Accordingly, the impact of the different procedures available for atmospheric correction on the retrieval of remote sensing reflectance (Rrs) data can then be evaluated based on satellite OC data acquired from the LISCO site over the last two years. From this, the qualities of different atmospheric correction procedures are assessed by performing matchup comparisons between the satellite OC data processed with the different correction procedures and LISCO data.

8372-22, Session 5

Airborne lidar as a tool for estimating inherent optical properties

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LIght Detection And Ranging (LIDAR) systems have been used most extensively to generate elevation maps of land, ice and coastal bathymetry. There have been space-, airborne- and land-based LIDAR systems. They have also been used in underwater communication. What has not been investigated are the capabilities of LIDARs to measure temperature and optical properties vertically in the water column, individually or simultaneously. The practical use of bathymetric LIDAR as a tool for the estimation of inherent optical properties remains one of the most challenging problems in the field of optical oceanography. LIDARs can retrieve data as deep as 3-4 optical depths (e.g. optical properties can be measured through the thermocline for ~70% of the world?s oceans). Similar to AUVs (gliders), UAV-based LIDAR systems will increase temporal and spatial measurements by several orders of magnitude. The LIDAR Observations of Optical and Physical Properties (LOOPP) workshop was held at NURC (2011) to review past, current and future LIDAR research efforts in retrieving water column optical/physical properties. This new observational platform/sensor system is ideally suite for ground truthing hyperspectral/geostationary satellite data in coastal regions and for model data assimilation.

8372-23, Session 5

Probing the subsurface ocean processes using ocean lidars

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Subsurface profiling LIDAR systems extends our understanding of ocean processes “below” the surface SST and ocean color. Time-gated LIDAR backscattering intensity has been shown to define the bio-optical ocean layers and characterize subsurface process. The interaction between the mixed layer depth (MLD) using vertical temperature structures and LIDAR optical layers provides a critical link between physical and bio-optical processes. We evaluated the capability of LIDAR penetration to reach the MLD on a global basis. Penetration depths of LIDAR were estimated using attenuation depths derived from global monthly ocean color averages which were assumed vertically homogenous. Climatology of LIDAR penetration depth was combined with the monthly mixed layer depth determined from the NCOM ocean circulation model. Global NCOM was run from 2002 - 2010 and MDL averaged on a monthly basis. Results show how monthly changes in MLD and LIDAR penetration depth are coupled for different regions of the global ocean. For example, the time-lag in LIDAR penetration depths is linked to shallowing of the MLD in the North Atlantic Bloom. We estimate the percentage that global ocean waters where different LIDAR system configurations can reach below the MLD. Results illustrate the potential performance of LIDAR systems to “probe” the subsurface for global waters which help in LIDAR design. Subsurface processes such as mixing and biological growth and decay have significant impact on what we observe at the ocean surface. LIDAR profiling should provide the new dimension for monitoring global ocean processes.

8372-24, Session 5

Airborne lidar sensing of internal waves in a shallow fjord

J. H. Churnside, National Oceanic and Atmospheric Administration (United States); R. D. Marchbanks, Cooperative Institute for Research in the Environmental Sciences (United States); J. H. Lee, National Oceanic and Atmospheric Administration (United States); J. A. Shaw, Montana State Univ. (United States); A. Weidemann, U.S. Naval Research Lab. (United States); P. L. Donaghay, The Univ. of Rhode Island (United States)

A dual polarization lidar was used to sense internal waves from a small aircraft. Internal waves are gravity waves that are formed by a vertical displacement of a density gradient in the ocean. If the perturbation is great enough, a nonlinear wave is produced and the balance between nonlinearity and dispersion can create a soliton-like wave packet. We observed nonlinear wave packets in West Sound, Orcas Island, Washington. In this region, a density gradient is formed in the summer by solar heating of the surface water. The perturbation is produced by strong tidal flow through a narrow, shallow channel at the mouth of the sound. Plankton layers form in association with the density gradients, and these layers produce an enhanced lidar return that moves up and down with the wave. We observed these internal waves with a lidar operating at 532 nm. They were much more visible when the receiver was polarized orthogonal to the transmitted laser pulse. This was the case whether linear or circular polarization was used, with no significant difference between the two cases. These internal waves were also visible to the naked eye, when the surface currents produced by the waves modulated the small surface waves that produce the apparent texture of the ocean surface.

8372-25, Session 5

Remote sensing of sound speed in the ocean via Brillouin scattering

E. S. Fry, Texas A&M Univ. (United States)

A Brillouin LIDAR approach to range-resolved, remote measurements of sound speed (and temperature) in the ocean is described. Realistic objectives are an accuracy of 0.2 m/s (0.1˚C) over a range of the order of 100 m in clear ocean with a range resolution of approximately 1 m. Our approach will provide high-resolution spectroscopic capabilities even in very severe acoustic/vibration environments; it is based on the use of edge filters to provide a high-resolution determination of the Brillouin frequency shifts. The simplest edge filters are molecular iodine absorption lines; they have been used for the laboratory data to be presented. But, even more promising are excited-state Faraday anomalous dispersion optical filters that are nearing fruition. Our transmitter is a commercial, injection seeded, frequency-doubled Nd:YAG laser that we have modified in two ways. First, we changed its operating temperature to obtain lasing at a frequency consistent with our choice of iodine absorption lines. Second, we implemented the Ramp and Fire technique we had developed so that the laser operates in a single longitudinal mode even when there are severe environmental disturbances. Test results clearly demonstrate the efficacy of this new concept.

8372-26, Session 5

Multichannel deconvolution for underwater synchronous scan lidar image enhancement

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Synchronous scanning LIDAR (pulsed laser line scan) is possibly the optimal extended range underwater imaging technique--both in terms of photon efficiency and turbid water performance. In this technique, the energy of each laser pulse is concentrated onto adjacent target elements to form the overall image in a serial fashion.

A novel receiver design for such imagers using multiple small low-cost photodetectors was recently developed by the authors with the objectives of maintaining good angular discrimination, daylight operations compatibility and extremely wide total field of view. Such imaging system architecture can be modeled as a single-input-multiple-output (SIMO) system. The use of advanced image processing techniques such as multi-channel deconvolution (MCD), actively studied in microscopy and astronomical imaging applications, can be adopted to reduce degradations such as blurring due to forward scattering and also possibly extend the practical imaging range in turbid water.

The proposed technique employs a multi-dimensional signal processing approach. The measured returning pulse first undergoes a wavelet based temporal denoising, followed by a bilateral filter based spatial noise reduction algorithm that uses pulses within a local spatial window and takes advantage of the spatial correlation among adjacent target elements. Such a filtering step eliminates the need to utilize multiple pulses on each target element to improve the signal SNR. Following noise reduction, MCD is then employed to further enhance the pulse target return using the impulse response for each angularly displaced photodetector. The impulse response is derived from the EODES time-history model with knowledge of the inherent optical properties. Finally the intensity of the target element needed for image formation is determined using the enhanced pulse.

The performance of the proposed technique, both the pulse SNR improvement from the spatio-temporal filtering and the pulse target return enhancement from MCD, especially in highly turbid waters, is explored. Extension of the technique to a semi-blind MCD is also considered.

8372-27, Session 5

A modulated-pulse laser for underwater detection, ranging, imaging, and communications

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The challenge in implementing laser imaging and communication systems underwater lies in the high variability of the ocean environment, where propagation of light in the ocean is complicated by absorption and scattering. In particular, scattering causes both spatial distortion (beam spreading and/or backscatter) and temporal dispersion (pulse spreading, or modulation loss). Each of these types of dispersions stands to decrease sensor performance (lower image resolution, lower operating

range, lower data bandwidth, etc.).

Historically, pulsed lasers or intensity modulated lasers have been used to accomplish these tasks. However recently, researchers at the Naval Air Warfare Center have been investigating a new, modulated pulse technique, which combines the two methods. For imaging, the modulated pulse improves contrast between the target and unwanted backscatter by marrying the best features of the pulsed (time discrimination/receiver gating), and intensity modulated (frequency discrimination) techniques. Furthermore, the new modulated pulse source has the flexibility to synthesize pseudorandom coded sequences, which is now being investigated for its utility in the underwater optical channel. For communication, the modulated pulse's flexibility of laser repetition rate, macro-pulse width, and modulation frequency provide link designers additional variables that can be used to adapt the output based upon the environment. A review of the current work being performed with this unique source will be presented, along with a discussion of laboratory results.

8372-28, Session 5

Polarization techniques for the retrieval of water parameters from above and below water polarimetric observations

A. Gilerson, A. Ibrahim, The City College of New York (United States); T. Harmel, Observatoire Océanologique de Villefranche sur Mer (France); A. Tonizzo, S. A. Ahmed, The City College of New York (United States)

The next generation of Ocean Color satellite sensors (PACE, NASA) will have polarization sensitive channels which will make possible to continue the time series of polarization acquisitions from space initiated by the French missions POLDER/PARASOL (CNES) and can be used to acquire additional information on ocean water constituents. The water attenuation coefficient is not retrievable by the exclusive use of the unpolarized measurements of the water-leaving radiance. However, we recently showed that the underwater degree of linear polarization (DoLP) can be fairly related to the absorption/attenuation ratio which enables us to achieve retrievals of the absorption and attenuation coefficients from measurements of the Stokes components of the upwelling underwater light field.

The relationship between the DoLP and the absorption/attenuation ratio is investigated based on vector radiative transfer simulations of the underwater polarized light field for several wavelengths in the visible part of the spectrum, for a complete set of viewing geometries, for various atmospheric conditions, and for varying water compositions and surface roughness. An algorithm to retrieve the underwater Stokes components and the DoLP from above-water measurements, which are significantly contaminated by the reflection of sky light on the ruffled sea surface, is also presented which is based on a priori knowledge of the AERONET aerosol retrievals. The algorithm was implemented for the above-water instrumentation of the Long Island Sound Coastal Observatory (LISCO) which couples hyperspectral polarimetric measurements of a customized HyperSAS instrument with a collocated AERONET system. Retrieval of absorption and attenuation coefficients is assessed on the basis of LISCO data and on coincident underwater measurements of water inherent optical properties and polarization components. Perspectives for satellite observation are finally delineated.

8372-29, Session 6

Biological thin layers: history, ecological significance and consequences to oceanographic sensing systems

J. M. Sullivan, WET Labs, Inc. (United States) and The Univ. of Rhode Island (United States); M. S. Twardowski, WET Labs., Inc. (United States); P. L. Donaghay, J. Rines, M. N. McFarland, The Univ. of Rhode Island (United States); S. Talapatra, J. Katz, The Johns Hopkins Univ. (United States); J. H. Churnside, National Oceanic and Atmospheric Administration (United States); A. Weidemann, U.S. Naval Research Lab. (United States)

Thin layers are water column structures that contain high concentrations of organisms (or particles) that occur over very small vertical scales (a few meters or less), but with large horizontal scales (e.g. kilometers). Thin layers are now known to be common phenomenon in a wide variety of environments and can be a critical component in marine ecosystem dynamics and functioning. While knowledge about their dynamics is important to our basic understanding of oceanic processes, thin layers can also have significant impacts on both oceanographic and defense related sensing systems, e.g. thin layers can affect underwater visibility, imaging, vulnerability, communication and remote sensing for both optical and acoustic instrumentation. This talk will review the history of thin layers research, their ecological significance, innovations in oceanographic instrumentation and sampling methodologies used in their study, and the consequences of their occurrence to oceanographic sensing systems.

8372-30, Session 6

Development of new fusion products using satellite infrared, visible, synthetic aperture radar and altimetry data during the Deepwater Horizon oil spill in the Gulf of Mexico, 2010

M. A. Roffer, G. A. Gawlickowski, M. A. Upton, Roffer's Ocean Fishing Forecasting Service, Inc. (United States); F. E. Muller-Karger, Univ. of South Florida (United States); G. Goni, J. Trinanes, National Oceanic and Atmospheric Administration (United States)

The development of new satellite visualization products for mapping the oil + dispersant + water mixtures in the Gulf of Mexico during the Deepwater Horizon oil spill (April - August, 2010) is presented. Due to the differing spatial and temporal resolution of satellite derived infrared (AVHRR and MODIS), visible (MODIS and MERIS), synthetic aperture radar and altimetry, as well as, the type of information provided and needed it was necessary to merge the different data.

The fusion facilitated mapping the oil and dispersant mixture and the surface current flow fields in the near field and far field over a variety of spatial (e.g. 75 m - 1.1 km) and temporal (1 hour - 10 day) scales. In situ visual observations and drifting buoys were used to validate the new products. The ability to identify water masses using their signature physical characteristics (primarily sea surface temperature, but also ocean color), as well as, the water masses' coherent Lagrangian structures using sequential image analysis was shown for near isothermal conditions in the Gulf of Mexico.

8372-31, Session 6

Navy coastal environmental sensing

T. E. Bowers, Naval Oceanographic Office (United States)

No abstract available

8372-32, Session 6

Tools required for ocean observing: the alliance for coastal technologies

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States)

The value of coastal and ocean observing is well documented. In particular, both the NOAA-led Integrated Ocean Observing System (IOOS) and the NSF-funded Ocean Observatories Initiative (OOI) have been established to address the management, safety, and scientific needs of the US and to better understand and predict changes to important ocean and coastal resources and processes. A foundation for successful ocean observing is access to, and implementation of, effective, reliable, and standardized sensors and sensor platforms to collect environmental data. The Alliance for Coastal Technologies (ACT) was therefore established by NOAA as partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensors and sensor platforms for monitoring and studying aquatic systems. ACT goals include: transitioning emerging technologies to operational use rapidly and effectively; maintaining a dialogue among technology users, developers, and providers; identifying technology needs and novel technologies; documenting technology performance and potential; and providing IOOS with information required for the deployment of reliable and cost-effective networks. These goals are accomplished by providing three basic services: (1) a third-party tested for evaluating existing and developing sensor and sensor platform technologies, (2) a comprehensive data and information clearinghouse on environmental technologies, and (3) a forum for consensus and capacity building through a series of annual workshops on specific technology topics. We will review the ACT program, highlight accomplishments, and discuss trends found during the evaluations of in situ sensors.

8372-33, Session 6

High resolution modeling using in-situ observations from sensor hosting and remote characterization (SHARC) solar and wave energy harvesting vehicle

S. Lingsch, Naval Oceanographic Office (United States)

No abstract available

8372-34, Session 6

Forecasting the ocean optical environment in support of Navy mine warfare operations

S. D. Ladner, R. Arnone, J. Jolliff, U.S. Naval Research Lab. (United States); B. Casey, QinetiQ Inc. (United States); K. Matulewski, Naval Oceanographic Office (United States)

A 3D ocean optical forecast system called TODS (Tactical Ocean Data System) has been developed to determine the performance of underwater LIDAR detection systems. TODS fuses optical measurements from gliders, surface satellite optical properties and 3D ocean forecast circulation models to extend the 2-dimensional surface satellite optics into a 3-dimensional optical volume including subsurface optical layers of beam attenuation coefficient (c) and diver visibility. Optical forecasts are combined with electro-optical identification (EOID) models to determine the underwater LIDAR imaging performance field used to identify subsurface mine threats in rapidly changing coastal regions. TODS was validated during a recent mine warfare exercise with one of the helicopter HM squadrons (HM-14). Results include the uncertainties in the optical forecast and lidar performance and sensor tow height predictions which are based on visual detection and identification metrics using actual mine target images from the EOID system. TODS is a new capability of coupling the 3D optical environment and EOID system performance and is crucial for the MIW community as a tactical decision aid and for operational planning for timeliness and efficiency in clearance operations.

8372-35, Session 7

Cross-calibrating Landsat 7 with Terra/MODIS over dark waters

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Since its launch, Landsat 7 (L7) has been continuously monitored via different calibration techniques to ensure it meets the science requirements for the demanding application areas. The majority of the applications, including agriculture and forestry, require a robust calibration for medium to high reflective targets. However, when imaging water resources, the question becomes whether the calibration coefficients are valid for the dark end of the calibration curve. Motivated by the Landsat Data Continuity Mission (LDCM) and its potential for providing long-term water studies, the calibration status of L7's reflective bands are examined using a cross-calibration method. The well-calibrated Terra/MODIS scenes of multiple dates/seasons were chosen to evaluate the corresponding L7 imagery in the apparent reflectance domain. Following relative geo-registration, homogeneous areas exhibiting identical atmospheric conditions were specified as calibration sites. The methodology was verified by a) applying a similar approach over a well-known calibration site and b) performing sensitivity analysis on the effects of the differences in the spectral response functions of the two sensors. The results showed that there is a need to investigate the calibration status of L7 over dark targets and that the calibration coefficients valid for bright targets may introduce large errors when retrieving water constituents. The corrected L7 data were further validated against MODTRAN-derived Top-of-Atmosphere (TOA) radiance values for water types of known optical properties. It is concluded that although L7's reflective bands are well calibrated for most applications, its calibration status should be quantified separately for water studies.

8372-36, Session 7

Over-water atmospheric correction techniques for Landsat's new OLI sensor

A. D. Gerace, J. R. Schott, Rochester Institute of Technology (United States)

The Operational Land Imager (OLI) is a new sensor being developed by the joint USGS-NASA Landsat Data Continuity Mission that exhibits an exciting potential to be used for monitoring Case 2 waters. With upgrades such as a Coastal Aerosol band, 12 bit quantization, and improved signal-to-noise, preliminary studies indicate that OLI should be radiometrically superior to its predecessors. Considering that OLI will have the traditional 30m resolution of other Landsat instruments, and that its data is free to the community, this sensor should be an invaluable tool for long-term monitoring of water quality in Case 2 waters, especially in the nearshore environment.

Through the use of simulated data, previous research indicates that OLI can retrieve the levels of three main water quality indicators (Chlorophyll, Suspended Materials, and CDOM) to within 7% of their expected range when atmospheric effects are ignored. Since the atmosphere typically represents a major source of error when quantifying water constituents from space, significant efforts have been made to develop techniques that will accurately remove atmospheric effects from OLI data. As OLI is an instrument designed for land-based studies, it will not be equipped with the appropriate bands required by traditional water-based atmospheric correction algorithms. This work presents a new atmospheric correction technique that was developed specifically for the OLI instrument. Preliminary results of a simulated case study indicate that when atmospheric effects are included, OLI can retrieve the levels of the three water parameters to within 15%, which is within the desired error range for this type of research.

8372-37, Session 7

Scanning flow cytometry reveals importance of scatter by large marine phytoplankton

M. N. McFarland, J. Rines, P. L. Donaghay, The Univ. of Rhode Island (United States); J. M. Sullivan, WET Labs, Inc. (United States)

Marine phytoplankton communities comprise numerous species with distinct cell sizes, shapes and intracellular structure. These morphological characteristics are fundamental to the complex ecology of species and can impact the inherent optical properties of ocean waters. Although lab and modeling studies have shown that morphology can affect the optical properties of cells, testing these models in natural populations requires measurements at the community and cellular levels. We examined the optical and morphological characteristics of natural phytoplankton communities in East Sound, WA using bulk optical measurements (WET Labs ac9 and bb3) and scanning flow cytometric analysis of individual particles (CytoBuoy). Scanning flow cytometry measures light scatter and fluorescence along individual particles and determines particle length by time of flight through the incident laser beam. High resolution optical profiles were used to guide sample collection from distinct phytoplankton communities in real time. Flow cytometric analysis of collected samples revealed dramatic variation of the size/abundance distributions of phytoplankton groups and non-algal particles, the distribution of pigments among cell size classes, and their relative contribution to total absorption and scattering. Results suggest that, due to their complex morphology, large phytoplankton cells are responsible for a larger proportion of forward and sideward light scatter than would be expected based on their abundance and size.

8372-38, Session 7

Low-cost, fluorescence-based microfluidic sensor for measurements of pCO2 in seawater

X. Ge, R. Henderson, Y. V. Kostov, G. Rao, Univ. of Maryland, Baltimore County (United States)

Global warming is caused by increasing amounts of greenhouse gases (mostly CO_2) discharged into the environment by human activity, which leads to ocean acidification and an increase in environmental temperature. Ocean acidification and rising temperatures can disrupt the water's ecological balance, killing off some plant and animal species while encouraging the overgrowth of others. To minimize the effect of global warming on local ecosystem, there is a strong need to implement ocean observing systems to monitor the invasion of anthropogenic CO_2 and the impacts thereof on ocean biological productivity. Here we describe a low-cost fluorescence-based microfluidic sensor for pCO_2 measurements with single digit ppm resolution. The system is exclusively made with low-cost optics and electronics so that it is affordable enough to be deployed in great numbers. To avoid the interference of the fluorescent substances in seawater, a two-chamber design was used. A fluorescent dye solution was first pumped into an equilibrium chamber, where it was exposed to flowing seawater across a gas-permeable membrane. Upon equilibration, the dye solution was transported subsequently to a measurement chamber for pCO_2 measurement. Due to the multiple performance-boosting strategies such as the ideal 90 separation between excitation and emission, the beam combiner, the reference photodetector, etc., single-digit ppm resolution was achieved despite low cost.

8372-39, Session 8

Stability augmentation and mosaic method of forward-scan sonar images

S. Xie, J. Luo, J. Chen, Y. XU, Shanghai Univ. (China)

In recent years, forward-scan sonar is widely applied to the underwater inspection, which is not subject to the influence of light and turbidity. For expanding the monitoring scope, the image sonar is generally mounted on the pan-tilt platform of a ROV (Remotely Operated Vehicle) or survey boat. However, there are still some problems such as: 1) The field-of-view is narrow, i.e. the horizontal view angle of DIDSON (Dual-frequency identification sonar) is 29°; 2) The dynamic change of a ROV or survey boat by the water flow will cause the target to escape from the sonar image easily; 3) The image sonar is fixed on the pan-tilt platform, and its position and posture are unceasingly changed. As a result of these problems, the obtained images may be distorted and not on the same plane. To solve the above problems, stability augmentation of pan-tilt platform based on the principle of bionic eye movements and a mosaic method of sonar images are presented. According to the principle of the vestibule-ocular reflex, an active compensation control system of the mechanical pan-tilt platform is developed. It can compensate the sonar image instability resulting from attitude variation of a ROV or survey boat during operation. Applying multi-sensor fusion technology can rectify the sonar images with different position and posture to be on a single geodetic coordinate frame for image registration and matching. Finally, sonar images can be mosaic. A stable large-scale sonar image can be obtained. Compared with the convention methods, the new method can improve the accuracy of the sonar image mosaics.

8372-40, Session 8

Sonar watermark embedding and detection: a sea trial report

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Spread spectrum embedding of a digital watermark in sonar waveforms has been previously reported [Mobasseri et al, IEEE OCEANS'10]. The principal property of a watermark-carrying sonar pulse is that it can be identified and authenticated by recovering the watermark from the received pulse and matching it to a library of known watermarks. There are three avenues for verification of the detectability of the watermark by the receiver, 1) Matlab simulation, 2) Sonar Simulation Toolset(SST) simulation or 3) sea trials. The watermark detection ROC curves reported previously have been largely produced in Matlab. However, Matlab alone is not equipped to replicate the complexities of an underwater channel that the sonar propagates through. This work reports on sea trials conducted off the coast of Ft. Lauderdale at the South Florida Ocean Measurement Facility, This paper describes two efforts, 1) design and generation of the watermarked pulse fitting the expected channel and 2) watermark detection results using in situ measured data. One of the primary constraints of the experiment was the narrowband (only 100Hz) of the on-ship sonar sensors. The acoustic channel comprising of range, sea bottom, depth, and sensor placements were first simulated in SST and the expected ROC curves were generated. LFM pulses of duration two seconds swept from 900Hz to 1000Hz were used. A total of 20 sets of pings were transmitted. Each set consisted of an unmarked pulse, watermark signal alone and the watermarked pulse. A wideband probe signal was transmitted separately for channel estimation purposes. Tests were conducted over a range of 7KM with watermark strength 35dB below the signal. As received pulses were delivered to us in complex form, a novel correlation detector in the complex plane is implemented to take advantage of phase information as well. Statistics collected over the 20 ping cycle produced a watermark false alarm rate of one in 20. Missed watermark rate came in higher at 5 out of 20. These rates were obtained with no a priori knowledge of the channel frequency response. In any practical implementation, such knowledge can be made available to the embedding algorithm.

8372-41, Session 8

Hawaiian sun in New Hampshire waters: a simulation of natural environmental settings

S. Pe'eri, G. T. Shwaery, The Univ. of New Hampshire (United States); R. H. Meyer, ArgenTech Solutions, Inc. (United States)

Simulation of natural oceanic conditions in a laboratory setting is a challenging task, especially when that environment is 5000 miles away and is south by 20° latitude. We present an attempt to replicate the solar radiation expected in tropical latitudes and clear waters to 30 m in depth using a 2.5 m deep engineering tank at the University of New Hampshire. The goals of the study were: 1) to configure an underwater light source that produced an irradiance spectrum similar to natural daylight with the sun at zenith under clear atmospheric conditions, and 2) to monitor water clarity and quantify its impact on water color as a function of depth. Irradiance was measured using a spectra-radiometer with a cosine receiver to analyze the output spectrum of submersed lamps as a function of distance. In addition, an underwater reflection method was developed to measure the diffuse attenuation coefficient in real time. Two water clarity types were characterized, clear waters representing deep, open ocean, and more turbid waters representing littoral environments. Results showed good correlation between the irradiance measured at 400 to 600 nm and the natural daylight spectrum at 3 m from the light source. This can be considered the water surface conditions reference. Using these methodologies in a controlled laboratory setting, we are able to replicate illumination and water conditions to study the physical, chemical and biological processes on natural and man-made objects and/or systems in simulated, varied geographic locations and environments.

8372-42, Session 8

Comparison of sea-level measurements using microwave radar and subsurface pressure gauge deployed in Mandovi estuary in Goa, central west coast of India

P. Mehra, Y. Agarvadekar, R. Luis, L. Nadaf, National Institute of Oceanography (India)

Sea level data is obtained from many remote and coastal locations using absolute pressure gauges. This necessitates the knowledge of the other physical processes which effect the sea level measurements using absolute pressure gauges at a particular location to insert the required corrections. Data from the radar and an absolute pressure gauge, sampled every 10 minute are obtained from Verem, Goa, over a period of one year (January 2009 to May 2010) to carryout comparative studies. The common technologies for sea-level measurements are: a stilling well and float, Pressure system, Acoustic system and Radar system. We have developed a station at Verem, Goa, where a sub-bottom pressure gauge, radar gauge and surface meteorological system are in operation.

However, the absolute transducer provides, total pressure including sea level and atmosphere pressure. The estimation of sea-level by using an absolute pressure gauge is depended on atmospheric pressure, water density and local gravity variations. Also most of the pressure transducers are sensitive to temperature and needs to have an in-built temperature sensor to compensate thermal drifts, else it is important to monitored sensor temperature, so as to incorporate corrections independently. However, in case of radar gauge, which is positioned well above the highest expected sea level and also the highest expected wave to avoid damages to the unit system. It measures the distance from sensor to the air/sea interface. The radar gauge has many advantages over traditional systems (IOC, 2006), as it makes a direct measurement of sea level. The effects of density and temperature variations, even in the atmosphere, are unimportant.

The comparative studies carried out indicates that the root mean square difference between the estimated sea level using radar and pressure gauge with atmospheric pressure correction is ~ 2.6 cm. The harmonic analysis over the two time- series produces similar residuals and tidal constituents. The results from the study indicate the importance of concurrent measurement of atmospheric pressure along with sub-bottom absolute pressure gauge. The radar gauge has advantages over other type of gauges with regard to easy installation, maintenance and also sea level measurements are absolute and could be given precedence in future applications.

8372-43, Session 8

Study of wind speed attenuation at Kavaratti Island using land-based, offshore, and satellite measurements

A. Joseph, National Institute of Oceanography (India); P. Rivonkar, Systems Electronics (India); T. M. Balakrishnan Nair, Indian National Ctr. for Ocean Information Services (India)

The role of dense coconut palms in attenuating the wind speed at Kavaratti Island, which is located in the southeastern Arabian Sea, is examined based on land-based and offshore wind measurements (U10) using anchored-buoy-mounted and satellite-borne sensors (QuikSCAT scatterometer and TMI microwave imager) during an 8-year period (2000-2007). It is found that round the year monthly-mean wind speed measurements from the Port Control Tower (PCT) located within the coconut palm farm at the Kavaratti Island are weaker by 15-61% relative to those made from the nearby offshore region. Whereas wind speed attenuation at the island is ~15-40% in the mid-June to mid-October south-west monsoon period, it is ~41-61% during the rest of the year. Wind direction measurements from all the devices overlapped, except in March-April during which the buoy measurements deviated from the other measurements by ~20°. U10 wind speed measurements from PCT during the November 2009 tropical cyclone "Phyan" indicated approximately 50-80% attenuation relative to those from the seaward boundary of the island's lagoon (and therefore least influenced by the coconut palms). The observed wind speed attenuation can be understood through the theory of free turbulent flow jets embodied in the boundary-layer fluid dynamics, according to which both the axial and transverse components of the efflux of flows discharged through the inter-leaves porosity (orifice) undergo increasing attenuation in the downstream direction with increasing distance from the orifice. Thus, the observed wind speed attenuation at Kavaratti Island is attributable to the decline in wind energy transmission from the seaward boundary of the coconut palm farm with distance into the farm. Just like mangrove forests function as bio-shields against forces from oceanic waves and storm-surges through their large above-ground aerial root systems and standing crop, and thereby playing a distinctive role in ameliorating the effects of catastrophies such as hurricanes, tidal bores, cyclones, and tsunamis, the present study provides an indication that densely populated coconut palms and other tall tree vegetation would function as bio-shields against the damaging effects of storms through attenuation of wind speed.

8372-44, Session 8

Statistical modeling of tropical cyclones' longevity after landfall in Australia

K. K. Saha, S. A. Wasimi, Central Queensland Univ., Rockhampton (Australia)

Most of the devastations wrecked by a tropical cyclone occur on land, and therefore, its longevity after landfall is of critical importance. Published literature identifies many factors including inland environmental characteristics that influence this longevity and power dissipation rate. These have been studied in this research in the context of tropical cyclones that hit Australian coasts during the period 1970-2003. For obvious reasons, tropical cyclones which manifested recurrence or multiple landfalls have been excluded. After performing correlation, regression, eigen analysis, and significance tests it has been found that storm intensity at landfall, translation speed, relative humidity, surface temperature, upper level divergence, and surface roughness are the

significant parameters, which yielded a coefficient of determination of 88 percent for the data. The concept of surface roughness is well understood, but hitherto, no consistent metric for the purpose of tropical cyclones' propagation existed, and therefore, this paper introduces a scheme of assigning surface roughness based on terrain characteristics.

8372-45, Session 8

Underwater text messaging and locating system for a network of divers

R. Narayanaswami, Scientific Systems Co., Inc. (United States); M. Stojanovic, Northeastern Univ. (United States); C. Gutierrez, Scientific Systems Co., Inc. (United States)

Divers executing strategic underwater missions as well as recreational divers have a great need for communication. Divers can communicate between themselves as well as to a surface boat, to share information, perform cooperative maneuvers and to call for help. In addition, it would be useful to know the location of all divers relative to the boat. Such capability will allow operators on the boat to guide divers in their maneuvers and provide immediate assistance during emergencies. We have investigated communication protocols for the development of iDiver, a wearable text messaging and diver location system. We assume traffic for the network of divers and surface boat is sporadic and not continuous. For this traffic model, we developed and investigated efficient communication protocols utilizing carrier sensing and random ALOHA coupled with power control. We developed a two-phase angle estimation algorithm for relative location estimation of the divers that showed good accuracy. An X-Y-Z array enables estimation of both azimuth and elevation angle, whereas a compact X-Y array is sufficient for only azimuth elevation estimation. We tested the iDiver protocols in an underwater simulation as well as in emulation over Wi-Fi on Gumstix cards. Boat to diver node communication was reliable with 95% reliability. Within-group diver communications was satisfactory and we expect across-group diver communications to be reliable for bursty traffic. In our studies, we limited the number of nodes to twelve, which is reasonable. The developed protocol and system architecture can be readily adapted for portable underwater acoustic communication and locating devices.

8372-46, Poster Session

Underwater laser range finder

A. Laux, L. J. Mullen, Naval Air Systems Command (United States); P. Perez, Clarkson Univ. (United States); E. P. Zege, B.I. Stepanov Institute of Physics (Belarus)

The conventional method used to detect the range to an underwater object is by sending and receiving some form of magnetic or acoustic radiation. However, these systems have limitations in the range resolution and accuracy they can provide under certain conditions. We are investigating optical techniques for underwater target ranging to overcome these limitations. The potential benefits of a laser-based range finder include high-directionality and covertness, speed of response, and the potential for high-precision, range-accuracy. These benefits have been exploited in the above-water environment where kilometer propagation ranges are achieved with sub-meter range precision. The challenge in using optical techniques in the underwater environment is overcoming the exponential loss due to scattering and absorption. While absorption extinguishes photons, scattering redistributes the light and produces a 'clutter' signal component from the surrounding water environment. Optical modulation techniques using compact laser diode sources are being investigated to help suppress this 'clutter' and provide accurate target range information in a wide range of underwater environments. These techniques take advantage of digital hardware to generate and process the modulation signal so that multiple configurations can be evaluated easily via software commands. To complement the experimental efforts, a theoretical model has been developed to help optimize the system parameters and test the performance of various configurations as a function of different water optical properties. Results from laboratory water tank experiments will be discussed and compared with model predictions.

8372-47, Poster Session

Microscope for researching underwater objects

A. D. Frolov, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation); O. A. Vinogradova, D. N. Frolov, Labor-Microscopes (Russian Federation)

In this publication we are presenting an idea of construction opto-information device with resolution about 1 micrometer - for researching underwater objects. We propose using method and technique of microscope.

In the water in static and suspension there are very many alive and nonliving objects. Researching of structure of this object in molecular level will allow extend sphere of knowledge people about the world. Water, which takes the biggest part of the earth's surface, till this day poorly understood. Poorly studied organisms that are inhabit the oceans, especially at the depth of more than 5-10 feet. Development of tools for detailed study of organic and inorganic ocean objects can become as popular as the event itself an invention of the microscope.

It is hard to imagine a person who is under the water looks under a microscope and study the structure of micro objects. But the study of micro structure is needed and it was under water at the depth where they usually are. It is obvious that the extraction of these objects from the depths and study on a conventional microscope (even with using an aqueous solution) will not give accurate information. Therefore, microscope should be placed on depth.

8372-48, Poster Session

Development of a low cost unmanned surface vehicle for military applications

A. E. Cadena, Jr., Ecuadorian Navy (Ecuador)

This paper describes the development of an USV (Unmanned Surface Vehicle) prototype that serves as an educational platform and can be use for coastal patrol and operations in the jungle. The USV length is less than 2 m and range of 5000 m. It's composed by the following modules: propulsion, power, motor driver, CPU, sensor suite, camera system, communication and weapon system. The weapon system is formed by an assault rifle and a rocket launcher with a fire control system. The assault rifle don't have mechanical moving parts, the bullets (7.62x51mm round) are electronically ignited. The CPU is an FPGA development kit. The USV can be operate in remote mode or fully autonomous. Results of some systems of the USV from laboratory and sea trials are show. The main motivation to develop an Unmanned Surface Vehicle (USV) in the Ecuadorian Navy is contribute to control the fuel traffic at the Colombian-Ecuadorian border and control the piracy at the Jambeli Channel. The use of manned vessel to control these areas is very difficult. The Jambeli Channel has hundreds of places that can be use by pirates to hidden. These places can not be accessible for the Coastguards Patrol Vessels and they are very dangerous because are ideal places for ambush. During an Interdiction Operation in the jungle, the forces can be vulnerable to a surprise attack; the USV is a tool to give an early warning to the forces. An USV can be a potential tool to detect clandestine shipboard in the middle of the jungle. Other application of an USV is to serve as an aggressor to practice the combat against asymmetric threats to our maritime forces and port infrastructure.

8373-01, Session 1

MesoDynamic Architectures (Meso) Program

J. Rogers, Defense Advanced Research Projects Agency (United States)

Performance requirements have driven mechanical, electrical, and optical devices to ever smaller spatial scales and shorter temporal scales. Leading the way, the semiconductor industry has pursued miniaturization to improve speed. Similar drives have reduced mechanical systems down to nanoscales and optical systems to the point where they may involve only tens of photons. At these scales the classical descriptions that worked so well at larger ones break down with the rise of unavoidable disorder, quantum mechanical effects, and physical effects that have always been negligible. These are opportunities to reach unprecedented levels of system performance by exploiting inherent mesoscopic characteristics, including quantum mechanical properties, collective dynamics, fluctuations and nonlinearities intrinsic to such scales, which introduce variability and reliability problems. The MesoDynamic Architectures (Meso) program seeks to address future Defense needs by exploiting unique dynamics emerging at mesoscopic scales, previously untapped physics, new states of matter, novel relationships between fields, and the importance of noise and nonlinearity. The program goal is to provide DoD with breakthrough technologies with unprecedented performance for unrivaled communication, sensing and computation amenable to use in environments with limited resources. The Meso program identifies 4 technical thrusts: (1) coherent collective dynamics, (2) efficient information transduction between sound, electricity/magnetism, and light for on demand use of their best properties, (3) feedback control over coherent quantum dynamics, and (4) nonlinearity, fluctuations and noise intrinsic to the mesoscales. This talk reviews the Meso program goals, the advances it has achieved, and the potential impact of these findings to particular applications.

8373-02, Session 1

Electrochemical quantum tunneling for electronic detection and characterization of biological toxins

C. Gupta, R. Walker, R. Gharpuray, M. Shulaker, Z. Zhang, M. Javanmard, R. W. Davis, B. Murmann, R. T. Howe, Stanford Univ. (United States)

This paper introduces a label-free, electronic biomolecular sensing platform for the detection and characterization of trace amounts of biological toxins within a complex background matrix. The mechanism for signal transduction is the electrostatic coupling of molecule bond vibrations to charge transport across an insulated electrode-electrolyte interface. The current resulting from the interface charge flow has long been regarded as an experimental artifact of little interest in the development of traditional charge based biosensors like the ISFET, and has been referred to in the literature as a “leakage current”. However, we demonstrate by experimental and theoretical modeling that this current is arises from the rate-limiting transition of a quantum mechanical electronic relaxation event, wherein the electronic tunneling process between a hydrated proton in the electrolyte and the metallic electrode is closely coupled to the bond vibrations of molecular species in the electrolyte. Different strategies to minimize the effect of quantum decoherence in the quantized exchange of energy between the molecular vibrations and electron energy will be discussed, as well as the experimental implications of such strategies. Since the mechanism for the transduction of chemical information is purely electronic and does not require labels or tags or optical transduction, the proposed platform is scalable. Furthermore, it can achieve the chemical specificity typically associated with traditional micro-array or mass spectrometry-based platforms that are used currently to analyze complex biological fluids for trace levels of toxins or pathogen markers.

8373-03, Session 1

Piezoelectronics: a novel, high-performance, low-power computer switching technoloogy

D. M. Newns, G. J. Martyna, B. G. Elmegreen, X. Liu, T. N. Theis, IBM Thomas J. Watson Research Ctr. (United States)

Current switching speeds in CMOS technology have saturated for 8 years due to power constraints arising from the inability of line voltage to be further lowered in CMOS below about 1 V. We are developing a novel switching technology based on piezoelectrically transducing the input, gate, voltage into an acoustic wave which compresses a piezoresistive (PR) material forming the device channel. Under pressure the PR undergoes an insulator-to-metal transition which makes the channel conducting, turning on the device. A piezoelectric (PE) transducer material with a high piezoelectric coefficient, e.g. a relaxor piezoelectric, is needed to achieve low voltage operation. Suitable channel materials manifesting a pressure-induced metal-insulator transition can be found amongst rare earth chalcogenides, transition metal oxides, etc.. Mechanical requirements include a high PE/PR area ratio to step up pressure, a rigid surround material to constrain the PE and PR external boundaries normal to the strain axis, and a void space to enable free motion of the component side walls. Using static mechanical modeling and dynamic electroacoustic simulations, we optimize device structure and materials and predict performance. The device, termed a PiezoElectronic Transistor (PET) can be used to build complete logic circuits including flip-flops, inverters and gates. This “Piezotronic” logic is predicted to have a combination of high speed and low power operation.

8373-04, Session 1

Communication and navigation applications of nonlinear micro/nanoscale resonator oscillators

J. Lovseth, T. Hoffmann, S. Kalyanaraman, A. Reichenauer, V. Olen, D. Hrncirik, Rockwell Collins, Inc. (United States)

Applications for high-performance micro/nanoscale resonator oscillators are examined. Oscillator phase noise has been improved using nonlinear techniques. Analyses and simulation are used to determine performance thresholds necessary for application of these devices in communication and navigation radios. Measured performance of actual radio products using prototype oscillators is used to verify models. A Rockwell Collins VHF air traffic control radio is modified and measured to accept prototype nonlinear oscillators as a frequency reference. Measured signal-to-noise+distortion (SINAD) improvement is equivalent to 236 km greater communication range in operational environments. A Rockwell Collins GPS navigation radio is modified and measured with the same oscillators. Oscillator frequency stability does not meet the required level to acquire and track GPS. Device improvements are suggested.

8373-05, Session 1

Dynamics-enabled quartz reference oscillators

D. Chang, H. P. Moyer, R. L. Kubena, R. J. Joyce, D. J. Kirby, P. D. Brewer, H. Nguyen, F. P. Stratton, HRL Labs., LLC (United States)

Stable local oscillators with low phase noise are extremely important elements in high performance military communication and navigation systems. For example, phase noise determines the range of radios and affects the signal acquisition time of GPS receivers. Under the DARPA Dynamics-Enabled Frequency Sources (DEFYS) program within the MesoDynamic Architectures (Meso) umbrella, the technical performers are tasked to develop compact UHF-band frequency sources capable of maintaining low phase noise under high accelerations or vibrations and over a wide temperature range for handheld portable systems by meeting the following end-of-program requirements: carrier frequency of 1 GHz, phase noise of -120 dBc/Hz @ 1 kHz offset, acceleration sensitivity of 1E-8 /g, frequency temperature coefficient of 3 ppm from -40 deg. C to 85 deg. C and a final volume of 1 cubic mm. The program also requires exploring nonlinearity in MEMS/NEMS resonators and attempts to use nonlinear dynamics to enhance phase noise performance. Using the quartz MEMS technology, we have thus far demonstrated a 645 MHz Pierce oscillator with -113 dBc/Hz phase noise at 1 kHz offset, acceleration sensitivity of 5E-10/g during the first phase of DEFYS development. The open-loop nonlinear operations of Duffing resonators under various drive levels and a companion theoretical model have been developed as well. The controlled oscillation of a nonlinear Duffing resonator in a closed-loop system will be presented.

8373-06, Session 1

Topological surface state: science and potential applications

A. Yazdani, Princeton Univ. (United States)

The approach is based on carrying out a diverse set of experiments that characterize the properties of topological surface states and their response to magnetic exchange interaction. These phenomena are combined in a device structure that can carry electrical current at the interface of a topological insulator and a magnetic overlayer. I will describe efforts made in understanding the science of such interface and realization of hybrid magent/topological insulators structures with device-like characteristics. To build these structures, we have assembled a strong multidisciplinary team whose expertise spans knowledge of the fundamental properties of topological (Bernevig, Cava, Hasan, Kane, Mele, Ong, and Yazdani) the growth and characterization of these novel materials (Cava, Samarth), and device fabrication including those that exploit magnetic nanostructures (Ong, Samarth, Ralph, and Worledge).

8373-07, Session 1

Coherent feedback control in nanophotonic circuits

H. Mabuchi, Stanford Univ. (United States)

Coherent feedback control theory utilizes the field-theoretic formalism of quantum stochastic differential equations to analyze and synthesize models of scattering networks with loops. Decades of work in quantum optics have given us a firm foundation for modeling individual input-output components, so we now have all the tools we need to describe nanophotonic circuits including both feed-forward and feedback connections. This presentation will focus on engineering analysis of multi-component circuit motifs for ultra-low power classical information processing, highlighting the enabling role of circuit-level phase coherence in the nanophotonic setting. I will discuss scalable design methodologies and the key role of input-output model reduction. The end of the talk will briefly shift to a discussion of quantum information processing in nanophotonic circuits, analyzed using the same formalism.

8373-08, Session 1

Topological materials and their applications in electronics

S. Zhang, Stanford Univ. (United States)

No abstract available

8373-09, Session 1

Piezoelectric nonlinear nanomechanical temperature and acceleration insensitive clocks

G. Piazza, A. Tazzoli, M. Rinaldi, J. Segovia, C. Cassella, B. Otis, J. Shi, K. L. Turner, C. Burgner, K. McNaul, V. Felmetsger, D. Bail, Univ. of Pennsylvania (United States)

This work presents the development of high frequency mechanical oscillators based on non-linear laterally vibrating aluminum nitride (AlN) piezoelectric resonators. Our efforts are focused on harnessing non-linear dynamics in resonant mechanical devices to devise frequency sources operating around 1 GHz and capable of outperforming state-of-the-art oscillators in terms of phase noise and size. To this extent, we have identified the thermal and mechanical origin of non-linearities in micro and nanomechanical AlN resonators and developed a theory that describes the optimal operating point for non-linear oscillators. Based on these considerations, we have devised 1 GHz oscillators that exhibit phase noise of < -90 dBc/Hz at 1 kHz offset and < - 160 dBc/Hz at 10 MHz offset. In order to attain thermally stable oscillators showing few ppm shifts from - 40 to + 85 °C, we have implemented an embedded ovenization technique that consumes only few mW of power. By means of simple microfabrication techniques, we have included a serpentine heater in the body of the resonator and exploited it to heat the device and monitor its temperature without degrading its electromechanical performance. The ovenized devices have resulted in high frequency stability with less than 150 ppm of shift over the temperature range of interest. Finally, a few of these oscillators were tested according to military standards for acceleration sensitivity and exhibited a frequency sensitivity lower than 20 ppb/G. These ultra stable oscillators with low jitter and phase noise will ultimately benefit military as well as commercial communication systems.

8373-10, Session 1

Topological insulator coherent energy devices

Y. P. Chen, Purdue Univ. (United States)

Topological insulators (TI) have gained strong recent interests as a novel class of materials, with gapped semiconducting bulk and topologically protected, spin-polarized high mobility metallic surface states. I will describe the progresses of our DARPA-funded MESO program that aims to take advantage of the novel properties of TI for low power, energy-efficient devices and energy-harvesting devices. Topics to be covered include: 1) access, characterize and control the TI surface state transport in gated TI field effect transistors, probing both the charge and spin transport; 2) gated TI thermoelectric devices (TED), particularly the role of topological surface state to potentially enhance the ZT figure of merit of TEDs;

3) gated TI excitonic devices with two coupled and complementary TI surfaces that may potentially realize excitonic condensate, a superconductor-like state that could lead to ultralow energy-efficient devices and systems.

8373-11, Session 2

Coherent wavelength translation with optomechanics

O. J. Painter, California Institute of Technology (United States)

In the last several years, rapid advances have been made in the field of cavity optomechanics, in which the usually feeble radiation pressure force of light is used to manipulate, and precisely monitor, mechanical motion. Amongst the many new geometries studied, coupled phononic and photonic crystal structures (dubbed optomechanical crystals) provide a means for creating integrated, chip-scale, optomechanical systems. Applications of these new nano-opto-mechanical systems include all-optically tunable photonics, optically powered RF and microwave oscillators, and precision force/acceleration and mass sensing. Additionally there is the potential for these systems to be used in hybrid communication networks, enabling storage or coherent transfer of information across disparate frequency bands. In this talk I will describe our recent efforts to use optomechanics to translate visible photons to the near-infrared, and near-infrared photons directly to the microwave regime.

8373-12, Session 2

Information transduction based on magnons

H. Tang, Yale Univ. (United States)

Magnons are bosonic quasiparticles of elementary magnetic excitations and can propagate several centimeters in YIG at a tunable velocity that is comparable to the sound velocity. Magnons as an information carrier can provide time delay and information storage functions, similar to phonons in acoustic devices. Magnon spectra are highly tunable. The geometrically defined spectra can be externally varied by changing the applied magnetic field. This external tunability offers significant advantages when interfacing with photonic cavities having discrete optical modes. In magnonics, a range of parametric processes are available for dynamical phase and coherence control of magnon propagation, such as parallel pumping, spin wave echo, wavefront reversal, and parametric phase reversal. Magnon storage and recovery via parametric modal conversion to standing wave mode with zero velocity has also been demonstrated. We also show that, beyond waveguide geometry, the magnon transmission can be further tailored by magnonic crystals that are analogous to photonic crystals.

Highly tunable microwave oscillator will be demonstrated by utilizing magnonic delay lines. This tunable oscillator comprises of an active magnon delay line as signal processing unit and utilizes electrical or optical feedback rings to coherently convert signal in between magnonic, optical or electrical domains. Phase noise reduction is enabled by high Quality factor in the active feedback rings.

8373-13, Session 2

Stimulated Mach-wave phonon emission: toward broadband phonon emitters and phonon lasers

P. T. Rakich, C. M. Reinke, R. M. Camacho, P. Davids, I. El-kady, R. H. Olsson III, D. W. Branch, R. L. Jarecki, Sandia National Labs. (United States); Z. Wang, Massachusetts Institute of Technology (United States)

We review the physics of photon-phonon coupling in guided wave systems, and discuss new opportunities for information transduction afforded by nanoscale confinement of light and phonons within a novel class of optomechanical waveguide systems. We present a fundamental analysis of optical forces generated through nanoscale light-matter interactions, and use these insights to develop new approaches for broadband signal processing via optomechanics. Recent experimental results will also be discussed

8373-14, Session 2

Nonlinear nanoelectromechanical systems

M. L. Roukes, California Institute of Technology (United States)

Advances in NEMS resonator technology demonstrate their significant potential for operation at very high frequencies and attainment of high quality factors, while consuming ultralow power. Our efforts toward development of low-noise frequency sources, which have culminated in our implementation of various self-sustained VHF NEMS oscillators, will be described. However, we first showed that NEMS demonstrate a progressively earlier onset of nonlinear behavior as their size is downscaled. Accordingly, realization of ultralow noise NEMS frequency sources requires both a detailed understanding and careful engineering of nonlinear NEMS dynamics. This talk will review our recent efforts in this area.

8373-15, Session 3

Basic research interests in nanoscale radiation sensing

C. Shipbaugh, Defense Threat Reduction Agency (United States)

The Defense Threat Reduction Agency's Basic and Applied Research Directorate supports grants to study nanoscale radiation indicators. Identification of the presence of radioactive materials is important for both defense and environmental concerns. Nanotechnology and related research areas offer new opportunities to control matter on an ultrafine scale. This enables the creation of unique “fingerprints” that may be recorded and checked. Processes that occur at a predictable rate allow the expected values or properties to be forecast and examined. Nanoscience may also enable improved understanding of energy storage or transfer processes that can be exploited for indicators of the status of a material, and to identify specific external forces influencing the structure and energy state of a material. Fullerene-based nanomaterials, quantum dots, nano-fibers, nanotubes, nano-sheets etc., can be functionalized to possess unique properties or characteristics. For example, nanoscale materials that emit spectral signatures in the presence of ionizing radiation or nuclear particles when incorporated in other widely used materials or objects, would assist in locating and securing radiological or nuclear materials. If the indicators are environmentally benign, they could be spread over wide areas where nuclear material is suspected, to identify specific locations.

8373-16, Session 3

Graphene for radiation sensing and rad-hard electronics

Y. P. Chen, Purdue Univ. (United States)

(This is an invited talk)

Graphene has emerged as one of the most remarkable and versatile materials in nanotechnology for its numerous unique properties and application potentials. We will present our studies on how charged and neutral ionizing radiations interact with and affect graphene and graphene-based materials and devices (particularly graphene field effect transistors) with various structures. For example, room temperature sensing of X-rays, gamma rays and light have been demonstrated in graphene transistors on appropriate substrates. Our studies have also yielded important results for the radiation-harness of graphene-based electronics.

8373-17, Session 3

Microstructured semiconductor neutron detectors

D. S. McGregor, S. L. Bellinger, B. Cooper, R. G. Fronk, T. J. Sobering, J. K. Shultis, Kansas State Univ. (United States)

Microstructured semiconductor neutron detectors offer a compact and viable technology for thermal neutron detection. The devices have microscopic patterns, etched into a semiconductor substrate, backfilled with neutron reactive materials. Neutrons interact in the backfill material, promptly releasing energetic reaction products that are detected in the surrounding semiconductor material. Various designs have been analyzed, generally having 15 micron wide symmetric patterns up to 500 microns deep. The detector microstructures were backfilled with compacted LiF material. The detectors were tested and calibrated in a 0.0253 eV diffracted neutron beam from the KSU TRIGA Mark II nuclear reactor, yielding intrinsic thermal neutron detection efficiency >21%, with stacked devices yielding 42% efficiency. The gamma-ray to neutron rejection ratio was 3x10^6 when tested with Co-60. Theoretical and experimental results will be presented and discussed.

8373-19, Session 3

Investigation of graphene-based nanoscale radiation sensitive materials

J. Robinson, M. Wetherington, M. LaBella, M. Bresnehan, Z. Hughes, D. W. Snyder, The Pennsylvania State Univ. (United States)

Current state-of-the-art nanotechnology offers multiple benefits for DoD applications. These include the ability to incorporate nano-sized radiation indicators into widely used materials such as paint, popular corrosion-resistant coatings, and ceramics to create nano-composite materials that can be widely used in everyday life. Additionally, nanotechnology may lead to the development of ultra-low power, flexible detection systems that can be embedded in clothing or other systems. Graphene, a single layer of graphite, exhibits exceptional electronic and structural properties, and is being investigated for high-frequency devices and sensors. Previous work indicates that graphene-oxide (GO) - a derivative of graphene - exhibits luminescent properties that can be tailored based on chemistry; however, exploration of graphene-oxide's ability to provide a sufficient luminescent response to gamma or neutron radiation has not been carried out. We are investigating the mechanisms of radiation-induced chemical modifications and radiation damage induced shifts in luminescence in graphene-oxide materials to provide a fundamental foundation for further development of radiation sensitive detection architectures. Additionally, we are investigating the integration of hexagonal boron nitride with graphene-based devices to evaluate radiation induced conductivity in nanoscale devices. This presentation will discuss: 1) the effects of material parameters such as C/O ratio, film morphology and structure, and defects on gamma and neutron radiation induced luminescence in graphene-oxide; and 2) acute effects of radiation on graphene-based nanoelectronics.

8373-20, Session 3

Nanocomposites for radiation sensing

B. K. Wagner, Z. Kang, J. Nadler, B. Kahn, R. Rosson, Georgia Tech Research Institute (United States)

The use of light emitting nanoparticles in polymer and glass matrices was studied for radiation detection. These nanocomposite scintillators were produced by various approaches including quantum dot/polymer, fluoride nanophosphor/epoxy and halide nanophosphor containing glass-ceramic composites. II-VI based quantum dots, synthesized by colloidal chemical techniques, were incorporated into polyvinyl alcohol, polystyrene and polymethylmethacrylate matrices at loading densities of 0.5 to 10wt% and sizes ranging from thin layers to 100cc. Cerium activated lanthanum and barium fluoride nanoparticles were also synthesized by chemical precipitation techniques. These materials were suspended in an aqueous colloidal solution or incorporated into epoxy matrix scintillators. An alternate technique to create nanocomposite scintillators that involved the fabrication of glass-ceramic composites was also studied. In this approach, halide based nanocrystals precipitate in-situ out of a glass melt upon cooling. Alumina and silica materials were mixed with gadolinium, calcium, cerium europium and terbium halides and heated to temperatures sufficient to melt the glass composition in an inert/reducing atmosphere. After heating, the glass melt was cast into graphite molds to produce scintillator structures. Post synthesis annealing was carried out to modify nanocrystal properties and light output. All scintillator materials were characterized by optical and structural techniques and promising samples exposed to x-ray sources and a series of gamma sources with energies ranging from 59 to 2500keV. In the case of the glass ceramic composites, clear gamma ray spectra were obtained for these radionuclides with a 662keV resolution of ~27% and gamma ray efficiencies equivalent to conventional NaI:Tl scintillators of similar dimensions.

8373-21, Session 4

Nanoscale chemical composition mapping of polymers at 100nm spatial resolution with AFM-based IR spectroscopy

K. Kjoller, C. B. Prater, M. Lo, Anasys Instruments (United States); A. Dazzi, Univ. of Paris-Sud-XI (France); R. Shetty, Anasys Instruments (United States)

Atomic force microscope (AFM) and IR Spectroscopy have been in combined in a new technology platform (AFM-IR) to map nanoscale chemical, structural and thermo-mechanical variations in polymers and other samples. The AFM-IR technique illuminates the sample with light from an infrared laser and measures the IR absorption of this light on a sub-wavelength scale using the tip of an AFM by detecting local thermal expansion of the sample. AFM-IR can be used both to obtain absorption spectra at arbitrary points and to spatially map IR absorption at selected wavelengths. Simultaneous measurement of the AFM cantilever's contact resonance frequency as excited by the IR absorption provides a complementary and simultaneous measurement of sample stiffness. The AFM-IR techniques have been used to chemically identify individual chemical components in polymer nanocomposites and multilayer films with spatial resolution as high as 100 nm. Using self-heating AFM cantilever probes we have been able to locally modify the state of a semicrystalline polymer and observe the resulting change in IR absorption spectra on the nanoscale. By changing the polarization of the incident laser source, we have also mapped variations in molecular orientation in individual sub-micron polymer fibers.

8373-22, Session 5

A revolution in DNA sequencing technologies: beyond the $1,000 genome

J. A. Schloss, National Institutes of Health (United States)

The initial sequencing of the human genome, completed in 2003, spurred an appetite for much more sequence to understand the contributions of human sequence variation to health and disease. But despite a 3 order of magnitude reduction since the beginning of the Human Genome Project, the cost of sequencing was too high to collect the very large numbers of genome sequences needed. In 2004, NHGRI/NIH launched programs to reduce the cost of sequencing a mammalian genome by 2 (in five years) and 4 orders of magnitude (in ten years). At $1,000 or less per complete genome, very large (thousands of individuals) studies would become practical even for rare variation, and sequencing could become practical for individualized medicine. Five years later, as a result of an intensive R&D endeavor stimulated by a modest NIH investment and substantial

investments by several companies worldwide, the initial goal of driving costs below $100,000 was achieved. Today the community is on course to meet or exceed the next goal. This presentation will briefly summarize technologies that are in high-throughput use worldwide to produce stunning amounts of sequence and related data, novel biological insights, and real clinical impact. The presentation will emphasize technologies, emerging and on the horizon, that employ nanotechnology and other novel fabrication approaches and reveal new science, that may provide human genome sequence data of the quality and cost, and with the turn-around time, needed for optimal applications in research and medicine.

8373-23, Session 5

Molecular targeting in childhood malignancies using nanoparticles

N. Satake, E. Diaz, UC Davis Medical Ctr. (United States); N. Nitin, Univ. of California, Davis (United States); J. Nolta, K. S. Lam, UC Davis Medical Ctr. (United States)

The goal of this project is to develop a novel cancer-targeted therapy using short interfering RNA (siRNA) nanoparticles (NPs) with cancer-specific ligands to selectively target the Max dimerization protein 3 (Mxd3, previously known as “Mad3”), which we believe is important for cell survival. We will test this novel therapeutic approach in human cancer xenograft mouse models using primary cancer tissue samples. We will create mouse models for acute lymphoblastic leukemia (ALL) and neuroblastoma, which are the two most common childhood malignancies. Using cell lines, we have developed an in vitro treatment targeting Mxd3 with siRNA: superparamagnetic iron oxide NP complexes (SPIO-NPs). We now propose to develop a novel Mxd3-targeted therapy with siRNA:SPIO-NPs and cancer-specific ligands in vivo. Dr. Kit Lam invented the one-bead-one-compound (OBOC) combinatorial library method to identify cancer cell surface-targeting ligands. With OBOC libraries, millions of different beads can be synthesized, each bead bearing up to 1013 copies of the same molecule. We have identified several ligand candidates for ALL and neuroblastoma. We have established a new ALL xenograft mouse model of patients’ leukemia cells with NOD/SCID/IL2Rγ-/- (NSG) mice. We have shown successful engraftment and maintenance of primary leukemia cells through serial transplantations by intra-bone marrow injection. We are currently developing a neuroblastoma mouse model. We will use these models to test our proposed targeted therapy directly on human cancer cells engrafted in the mice.

8373-24, Session 5

Solid state nanopore sensors for DNA analysis

R. Bashir, Univ. of Illinois at Urbana-Champaign (United States)

Solid state nanopore sensors are promising sensor platforms for detection of single molecule DNA characterization and sequencing. We report the development of a multilayered graphene-Al2O3 nanopore platform for the sensitive detection of DNA and DNA-protein complexes. Graphene-Al2O3 nanolaminate membranes are formed by sequentially depositing layers of graphene and Al2O3 via atomic layer deposition. Subsequently, nanopores were formed in these stacked membranes using an electron-beam sculpting process. The resulting nanopore architecture is mechanically robust, exhibits low electrical noise and is highly sensitive to electrolyte pH at low KCl concentrations, attributed to the high buffer capacity of Al2O3. In proof-of-principle biomolecule sensing experiments, the folded and unfolded transport of single DNA molecules and RecA coated DNA complexes could be discerned. The process described here also enables nanopore integration with new graphene based structures, including three and four terminal nanoribbons and nanogaps, for medical diagnostic applications and DNA sequencing.

8373-25, Session 5

Fabrication and characterization of a solid state nanopore with self-aligned carbon nanoelectrodes for molecular detection

S. D. Collins, P. S. Spinney, Univ. of Maine (United States); D. G. Howitt, Univ. of California, Davis (United States); R. L. Smith, Univ. of Maine (United States)

The nanofabrication and characterization of a solid-state nanopore with integrated carbon nanoelectrodes for DNA and nanoparticle detection is presented. The nanofabrication employs a unique self-aligned process to precisely register nanopore to nanoelectrodes, and thereby mitigates many problems inherent in previous nanopore/electrode embodiments. A time correlated detection between blocking and tunneling currents is used to distinguish between DNA transits and spurious signals. Electrochemical characterization of the device indicates that the primary current mechanism between electrodes is thermionic emission. The detection of gold nanoparticles, lambda dsDNA, and short (16 base) ssDNA is demonstrated.

8373-26, Session 5

MRI-guided, ultrasound-mediated drug delivery to solid tumors: current problems

N. Rapoport, The Univ. of Utah (United States)

During the last decade, the development of stimuli responsive nanoparticles has provided for spatial and temporal control of tumor therapy. Nanoparticles allow combining drug carrying, tumor targeting, imaging, and therapy monitoring in the same nanoconstruct. Both passive and active targeting of nanoparticles to solid tumors may be realized. Passive targeting is based on defective tumor microvasculature that provides for the enhanced penetration and retention of nanoparticles in tumor tissue. After tumor accumulation, drug release from a carrier is triggered by intrinsic or extrinsic stimuli, e.g. tumor-directed ultrasound. Ultrasound-responsive multifunctional drug-loaded perfluorocarbon nanoemulsions have been developed in the author’s lab; perfluorocarbon nanodroplets combine properties of tumor-targeted drug carriers, ultrasound and 19F MRI contrast agents, and enhancers of ultrasound-mediated drug delivery. Under the action of ultrasound, nanodroplets convert into microbubbles and release their drug load into tumor tissue. The technology is extremely versatile; a wide range variation of nanodroplet structures and ultrasound parameters is possible. Effective regression of breast, ovarian, and pancreatic tumors in mouse models was achieved using this technology. However, many features of mechanisms involved in the ultrasound-mediated drug delivery have remained obscure, which delayed translation to clinics. Mechanistic studies by a multidisciplinary team of investigational radiologists, bioengineers, and surgeons are currently in progress at the University of Utah. Tumor treatment under the MRI control provides anatomical information for ultrasound focusing as well as allows treatment monitoring and control by the MRI thermometry. A dual role of ultrasound has been revealed, which requires fine tuning of treatment parameters for effective tumor therapy.

8373-27, Session 6

MEMS- and LC-adaptive optics at the Naval Research Laboratory

S. R. Restaino, C. C. Wilcox, T. Martinez, J. R. Andrews, F. Santiago, U.S. Naval Research Lab. (United States); D. M. Payne, Narrascape, Inc. (United States)

The Remote Sensing Division of the Naval Research Laboratory is involved in various imaging programs that require the use of Adaptive Optics (AO) to mitigate the effects of dynamically varying aberrations. Our programs range from Astronomical type of AO to horizontal path correction, etc. The bulk of our AO systems are centered on mirco-electro-mechainical (MEMS) and Liquid Crystal devices. In this paper we will present a status report of these programs and will discuss the future direction that we envision. In addition, lessons learned, pros and cons for different approaches will be discussed.

8373-28, Session 6

Closed-loop performance of an actuated deformable carbon fiber reinforced polymer mirror

C. C. Wilcox, U.S. Naval Research Lab. (United States); M. E. L. Jungwirth, D. V. Wick, M. S. Baker, C. G. Hobart, Sandia National Labs. (United States); R. C. Romeo, R. N. Martin, Composite Mirror Applications, Inc. (United States)

The Naval Research Laboratory and Sandia National Laboratories have been actively researching the use of carbon fiber reinforced polymer material as optical elements in many optical systems. Active optical elements can be used to build an optical system capable of changing is optical zoom. Two active optical elements that can change in radius of curvature can be used to achieve optical zoom. We have developed an optical system that uses a large diameter, thin-shelled carbon fiber reinforced polymer mirror actuated with micro-positioning motors and a high actuator density micro-electro-mechanical deformable mirror. Through the use of a Shack-Hartmann wavefront sensor, we have optimized this actuated carbon fiber reinforced polymer deformable mirror's surface for use with our reflective active optical zoom system. In this paper, we present the preliminary results of the carbon fiber reinforced polymer deformable mirror's surface quality and the development of the actuation of it.

8373-29, Session 6

Theory and design of a MEMS-enabled diffraction limited adaptive optical zoom system

M. E. L. Jungwirth, College of Optical Sciences, The Univ. of Arizona (United States); D. V. Wick, Sandia National Labs. (United States)

Active optical elements are used to induce a spatially varying phase shift in incoming wavefronts. One common active element is a deformable mirror (DM), where the physical shape of the surface is altered to change the element optical power. If two or more DMs are used in concert, an adaptive optical zoom system can be achieved, where system magnification is modified via variable focal length elements. Conventional zooming systems move elements along the optical axis, or rotate elements in and out of the optical train, which can be difficult with large diameter optics.

Theoretical descriptions of such systems are few. A natural fit for adaptive optical systems is the vector aberration theory as applied to bilateral systems, where only one plane of symmetry exists. This theory applies since it can easily handle both axial and non-axial (unobstructed) optical designs.

Micro-electro-mechanical systems (MEMS) DMs are well-known for their large stroke and precision. In fact, MEMS DMs can simulate Zernike surfaces up to a few radial orders, allowing correction of a wide range of aberrations. Recent experimental and theoretical research has proven MEMS DMs ability to provide real-time wavefront correction.

This paper extends the bilateral system theory to design a diffraction limited adaptive optical zoom system using variable focal length mirrors and MEMS DMs. In addition to wavefront correction, MEMS DMs enable less elaborate aspheric surfaces, increased element and spacing tolerances, and superb performance across a broad spectral range. A few designs in ZEMAX will be presented to demonstrate the theory.

8373-30, Session 6

Unconventional adaptive optics at the University of Arizona

M. Hart, O. Guyon, J. L. Codona, S. M. Ammons, The Univ. of Arizona (United States)

We describe the range of research in innovative techniques for high resolution imaging with adaptive optics (AO) being undertaken at the University of Arizona's Center for Astronomical Adaptive Optics. Scientific motivations for the work extend from the detection of earthlike planets around other nearby stars through studies of quasar host galaxies, as well as non-astronomical applications such as retinopathy and horizontal imaging for defense and security. We describe how high resolution imaging is delivered over an unusually wide field of view by ground-layer AO. This technique employs multiple laser guide stars to sense the instantaneous three-dimensional distribution of atmospheric turbulence. Imaging with high signal-to-noise ratio in the thermal infrared is enabled by use of a unique deformable mirror embedded in the telescope optics. Additional work has led to high contrast imaging for faint object detection by manipulation of the optical phase to redistribute light in the focal plane, creating very dark regions of the point-spread function. We also describe recent work to develop a new generation of robust lightweight deformable mirrors based on composite materials which shows promise for greatly reducing the cost of AO and broadening its appeal, particularly for non-astronomical applications.

8373-31, Session 6

Implementation of a phase-only, spatial-light modulator (SLM) for an atmospheric turbulence simulator at the short wavelength infrared (SWIR) regime

C. O. Font, C. C. Wilcox, F. Santiago, G. C. Gilbreath, D. Bonanno, U.S. Naval Research Lab. (United States)

Modeling and simulating the atmosphere in a controlled environment has been in the interest of scientists for decades. The development of new technologies allows performing this task in a more realistic and controlled environment, providing a powerful tool for the study and better understanding of the propagation of light through the atmosphere. Technologies like Free-space laser communications (FSLC) and/or studies on light propagation through the atmosphere are areas which constantly benefit from breakthroughs in the development of atmospheric turbulence simulators. In this paper we present the results of the implementation of a phase only spatial light modulator (SLM) as an atmospheric turbulence simulator at the Short-Wave Infra-Red (SWIR) regime and its use with a FSLC system.

8373-33, Session 7

Materials development for radiation detection

C. Lee, Raytheon Co. (United States)

Nuclear or radiological threat is a growing concern for U.S. national security, driving a need for high performance radiation detectors for nuclear materials. Among several technologies for the spectroscopy and imaging of ionizing radiation, technologies utilizing scintillation light or electric current output from solid state materials under radioactive excitation are very useful methods. The ideal scintillation materials should possess high scintillation efficiency, high light yield, excellent transparency, fast decay time, large-size scalability, and index-matching

for optimal light coupling. More importantly, it is imperative to develop environmentally durable detection materials that maintain high detection efficiency for global radiation monitoring systems. Electric current detection through the use of semiconductor or halide materials provides high resolution spectroscopy and imaging capability although there are scalability and cost issues. Ceramic oxide processing offers particularly compelling advantages to overcome size and homogeneity issues. . Raytheon has long been a leader in optical ceramic and semiconductor materials research and development. In this work, we will present current status of radiation detection materials and introduce our efforts for the development of ceramic scintillator materials.

8373-34, Session 7

Electrochemical, high-temperature gas sensors

B. Saruhan-Brings, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

This work presents the results obtained from the sensor electrodes prepared by reactive sputtering and have thin Cr- and Al-doped TiO_2 and Al-doped SnO_2-layers. By changing the coating parameter during magnetron sputtering, the sensing ability of thin layered NO_2-sensory can be improved significantly. This work displays the influence of surface structuring as well as chemical and crystallographic changes on the sensors response behaviour. Sensor characteristics towards NO and NO_2 were tested at the temperature range of 300°-900°C, depending on the application and material. Doping of semiconducting metal oxides resulted in the alteration of microstructure and phase sequence, consequently in the sensing properties of the electrode material. Moreover, the function of the sensor in context of the NO_x-reducing catalyst material was also evaluated. Sensing properties of the semi-conducting oxide electrodes can be adjusted by tailoring the doping to yield the specific sensing abilities.

Component integration of the sensing layers can be realized by means of sensor arrays, relying on thin-layering and compositional homogeneity of the sensing materials. Real-time signals from combustion and emission gases (e.g. NO_x) are required for establishment of a basis to develop more sophisticated control procedures. For that, such gas sensors are developed that can be embedded in EB-PVD TBCs which will serve as a part of the sensor systems. This multifunctional layer systems are proved to yield high sensitivity high-temperature NO_x-sensors and low thermal conductivity protective coatings.

8373-35, Session 7

Graphene-based chemical sensors

N. A. Koratkar, Rensselaer Polytechnic Institute (United States)

In this talk I will report on the gas sensing capabilities of individual Chemical vapor deposition (CVD) grown graphene sheets deposited on silicon oxide substrates. The sheets were lithographically contacted to electrically address the sample. Gases such as NO_2 and NH_3 can be detected in mixtures with air at room temperature and atmospheric pressure by simply monitoring real-time changes to the electrical conductivity of the sheet. The CVD-graphene sensor has the advantage of ultra-high sensitivity and shows the ability to detect trace amounts of gaseous molecules in mixtures with air at the parts-per-billion (ppb) level at room temperature and atmospheric pressure. In addition we have also studied the gas sensing capabilities of a 3D macro graphene network also grown by CVD which is far easier to contact and use and requires no lithographic patterning. The 3D network enables detection of a range of gas species at the parts-per-million (ppm) level. Further we show that Joule heating can be used on the graphene devices to expel chemisorbed gas molecules leading to fully reversible operation.

8373-36, Session 7

Nano/bio-hybrids for all electronic chemical detection

A. C. Johnson, Univ. of Pennsylvania (United States)

We have explored all-electronic chemical detectors based on bio-nano hybrids, where the biomolecule (DNA or protein) provides chemical recognition and a carbon nanotube (NT) or graphene transistor is used for electronic readout. This sensor class has numerous favorable properties and is a promising approach towards sensitive detection of liquid- and vapor-phase anayltes. NT or graphene transistors are functionalized with proteins through an amide bond using a reliable and robust process based on carboxylated diazonium salts. If desired, control of protein orientation is achieved through the use of a Ni-nitrilotriacetic acid (Ni-NTA) chemistry with affinity for the histidine tag on an engineered protein. We have used this approach to create a nanoelectronic interface to olfactory receptor proteins (ORs) that were embedded in synthetic nanoscale cell membrane analogues. Olfactory receptor proteins (ORs) are the most numerous class of G-protein coupled receptors (GPCRs), a large family of membrane proteins whose roles in the detection of molecules outside eukaryotic cells and initiation of cascades of intracellular responses make them important pharmaceutical targets. We have also very recently used similar methods based on an engineered antibody to demonstrate detection of a cancer biomarker at levels of 1 pgm/mL, 500 times smaller than the antibody dissociation constant. Non-covalent functionalization of carbon nanotube transistors is achieved through self-assembly of monolayers of single-stranded DNA on the NT sidewall. The DNA is used not for its self-recogntion properties but rather for its chemical recognition for small molecule analytes. We will discuss the possible use of this system for an "electronic tongue" system for detection of small molecule targets in aqueous media. Finally I will describe progress towards high-yield fabrication of large arrays of nanotube-based chemical sensors.

8373-37, Session 7

The process of developing an instrument: the JPL electronic nose

M. A. Ryan, Pacific Northwest National Lab. (United States)

The JPL ENose is a sensing array designed to monitor the environment for the sudden release, such as leaks or spills, of targeted chemical species. From 1995 to 2008, the ENose was developed at the Jet Propulsion Laboratory (JPL). The JPL ENose was taken from basic exploratory research into polymer-carbon composite chemiresistive sensors to a fully operating instrument which was demonstrated on the International Space Station (ISS). There were three generations of the instrument, with the First Generation developed for a six-day space shuttle demonstration in 1998, followed by extensive laboratory testing of the Second Generation, and a seven month ISS demonstration in 2008-2009.

The Third Generation JPL ENose was designed to detect, identify and quantify eleven chemical species, three inorganic, ammonia, mercury and sulfur dioxide, and eight organic compounds which represent common classes of organic compounds such as alcohols, aromatics, and halocarbons. Chemical species were quantified at or below their 24 hour Spacecraft Maximum Allowable Concentrations (SMAC), generally in the parts-per-million range; some targeted species were detected in the parts-per-billion range.

This talk will focus both on the technical capabilities of the Third Generation JPL ENose and on the process of taking exploratory research from the lab to a fully operational instrument.

8373-38, Session 8

Materials research at DARPA

B. C. Holloway, Defense Advanced Research Projects Agency (United States)

The Defense Advanced Research Projects Agency (DARPA) identifies and advances radically new technologies that promise to revolutionize military capabilities. The intent of this presentation is to communicate to the audience how to engage DARPA as it works towards addressing the grand challenges intrinsic to materials science. Topics to be covered will include ongoing DARPA led materials programs in the areas of materials for mission-critical portable power and energy, surface science, and advanced structural fiber, followed by a prospective on how novel materials science concepts can generate DARPA innovation

8373-39, Session 8

Light management on industrial-size c-Si solar cells by Si nanowires fabricated by electroless etching

R. Turan, M. Kulakci, B. Ozdemir, H. E. Unalan, Middle East Technical Univ. (Turkey)

Light trapping is becoming increasingly important in the photovoltaic solar cells as the device thickness is made thinner to reduce the material cost. Light trapping techniques aim at increasing the path length and the number of scattering events of the incident photons, thereby increasing the light absorption. Both reflection and transmission through the cell are significantly reduced in this way. Recently, it has been shown that vertically aligned Si nanowires can effectively be used for light trapping applications in crystalline and thin film solar cell systems.

In this work vertically aligned Si nanowires have been fabricated over large areas using an electroless etching (EE) method, which involves etching of silicon wafers in a silver nitrate and hydrofluoric acid based solution. After a detailed parametric study, they were applied to industrial size (156 mm x 156 mm) solar cells. The reflectivity of the device surface was reduced to almost zero for the whole visible spectrum including the blue-violet region. This has blackened the cell’s surface completely. Standard solar cell fabrication procedures have been followed to produce cells with and without nanowires. We found that the nanowire-decorated solar cells reach similar efficiency values as the standard pyramid textured cell, showing the potential of the technique. Optimization studies are needed to improve the device performance. It is found that the metallization needs a special attention due to poor contacting on nanowires.

8373-40, Session 8

Tailoring absorption and emission properties in semiconductor nanowires with nanocavity plasmons for photovoltaic applications

R. Agarwal, Univ. of Pennsylvania (United States)

Controlling the optical properties of semiconductors with an engineered surface plasmon cavity is of great importance for understanding the underlying physics and designing new nanoscale optoelectronic devices such as highly efficient photovoltaics. In this talk we will demonstrate highly enhanced absorption and also emission from single CdS-SiO2-Ag core-shell plasmonic nanowires, properties of which are different from simple photonic CdS nanowires. We will demonstrate that by fabricating a complete nanoplasmonic cavity, drastically enhanced absorption in comparison to metal nanoparticles attached to the nanowires is obtained due to the optical antenna effect, which can be tuned completely by controlling the nanowire size. Likewise, by tuning the plasmonic cavity size to match the whispering gallery mode resonances, an almost complete transition from thermalized excitonic to hot-excitonic emission can be achieved, which reflects exceptionally high radiative rate enhancement. Time-resolved measurements for the plasmonic nanowires showed the excited-state lifetime shortening by a factor of ~10000, resulting in sub-picosecond lifetimes. Numerical calculations also confirmed that the electromagnetic field enhancement by the whispering gallery plasmon nanocavity is as high as 40000 in these structures. This observation indicates that the intrinsic optical properties of semiconductors can be engineered by their interaction with nanocavity plasmons and is important for understanding and designing nanoscale optoelectronic devices with novel properties.

8373-41, Session 8

Multijunction nanowire solar cells based on III-V nanowire arrays synthesized using MOCVD

C. Zhou, The Univ. of Southern California (United States)

Recently nanomaterials have emerged as a building block for constructing next generation of photovoltaic devices. Nanowire based semiconductor solar cells, among other candidates, have shown potential to produce high efficiency solar cells. Application of nanowires can increase choice of materials one can use to fabricate high efficiency solar cell by relaxing the lattice mismatch constraint. Here we report a scalable method of fabricating vertical III-V semiconducting nanowire arrays using Selected Area Metal Organic Chemical Vapor Deposition (SA-MOCVD) technique which can find application in various optoelectronic devices. We use nanosphere lithography patterning techniques to obtain highly ordered pattern for SA-MOCVD and demonstrate wafer-scale fabrication of GaAs nanowires on Si (111) substrate. We also compared various optical and electrical properties of these nanowires with the nanowires grown by using E-beam patterned substrates which is a more conventional but expensive and slow techniques. Guided by optical and electrical modeling, we fabricated single junction GaAs nanowire solar cell on Si substrate and multijunction GaAs nanowire and silicon tandem solar cell. The effect of surface passivation of nanowires on the performance of the devices was also studied. Nanowire synthesis, device fabrication and characterization will be discussed in detail.

8373-42, Session 8

Silicon-based bulk nanostructured thermoelectric generators

A. Boukai, Univ. of Michigan (United States)

State-of-the-art thermoelectric generators are typically based on exotic alloys and have low device efficiencies. Therefore, research targeting new discoveries in earth abundant thermoelectric materials that increase device efficiency are needed. This talk will present recent progress on bulk nanostructured thermoelectric materials that are silicon-based. These include functional silicon nanowire devices and silicide/silicon eutectics. These bulk nanostructured thermoelectric devices exploit dramatic reductions of thermal conductivity due to phonon scattering at disordered interfaces, which is expected to increase ZT. Thermoelectric properties, structural characterization, and device efficiencies will be presented.

8373-43, Session 9

Applying systems engineering methodologies to the micro- and nanoscale realm

M. A. Garrison-Darrin, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Micro-scale and nano-scale technology developments have the potential to revolutionize smart and small systems. The application of systems-engineering methodologies that integrate standalone, small-scale technologies and interface them with macro-technologies to build useful systems is critical to realizing the potential of these technologies. This talk covers the expanding knowledge base on Systems Engineering principles for micro- and nano-technology integration. Technology development on the microscale and nanoscale has transitioned from laboratory curiosity to the realization of products in the health, automotive, aerospace, communication, and numerous other arenas.

Developing systems engineering methodologies that integrate stand-alone, small-scale technologies and interface them with macrotechnologies to build useful systems is critical to realizing the potential of micro- and nanoscale devices. A barrier to the infusion of the micro- and nanotechnologies into systems is a lack of insight into how to apply systems engineering principles for technical developments and management processes to the integration of small-scale technologies. The result of this first-step is provision of practical guidance for systems engineers in the development of micro- and nanotechnologies. For nonconventional micro- and nanoscale systems, the systems engineer must also be knowledgeable about the roles of nonconventional disciplines, such as quantum mechanics, quantum chemistry, solid-state physics, materials science, and chemistry, in the development of small-scale systems. The results are also targeted toward small-scale technology developers who need to take into account systems engineering processes, such as requirements definition, product verification and validation, interface management, and risk management, in the concept phase of technology development to maximize the likelihood of successful, cost-effective micro- and nanotechnology to increase the capability of emerging deployed systems and long-term growth and profits. Contributors in this introductory first step include nanotechnologists, physicists, systems engineers, material scientists, chemists, electrical engineers, and futurists.

8373-44, Session 9

Leveraging scale effects to create next-generation photovoltaic systems through micro- and nanotechnologies

G. N. Nielson, Sandia National Labs. (United States)

Current solar power systems using crystalline silicon wafers, thin film semiconductors (i.e., CdTe, amorphous Si, CIGS, etc.), or concentrated photovoltaics have yet to achieve the cost reductions needed to make solar power competitive with current grid power costs. To overcome this cost challenge, we are pursuing a new approach to solar power that utilizes micro-scale solar cells (5 to 20 microns thick and 100 to 500 microns across). These micro-scale PV cells allow us to take advantage of beneficial scaling effects that are manifested at the cell, module, and system level. Examples of these benefits include improved cell performance, better thermal management, new module form-factors, improved robustness to partial shading, and many others. To create micro-scale PV cells we are using technologies from the MEMS, IC, LED, and other micro and nano-system industries. To date, we have demonstrated fully back-contacted crystalline silicon (c-Si), GaAs, and InGaP microscale solar cells. We have demonstrated these cells individually (c-Si, GaAs), in dual junction arrangements (GaAs, InGaP), and in a triple junction cell (c-Si, GaAs, InGaP) using 3D integration techniques. We anticipate two key systems resulting from this work. The first system is a high-efficiency, flexible PV module that can achieve greater than 20% conversion efficiency and bend radii of a few millimeters (both parameters greatly exceeding what currently available flexible PV can achieve). The second system is a utility/commercial scale PV system that cost models indicate should be able to achieve energy costs of less than $0.10/kWh in most locations.

8373-45, Session 9

Systems engineering at the nanoscale

J. J. Benkoski, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Nanomaterials have provided some of the greatest leaps in technology over the past twenty years, but their relatively early stage of maturity presents challenges for their incorporation into engineered systems. Perhaps even more challenging is the fact that the underlying physics at the nanoscale often run counter to our physical intuition. The current state of nanotechnology today includes nanoscale materials and devices developed to function as components of systems, as well as theoretical visions for “nanosystems,” which are systems in which all components are based on nanotechnology. Although examples will be given to show that nanomaterials have indeed matured into applications in medical, space, and military systems, no complete nanosystem has yet been realized. This talk will therefore focus on systems in which nanotechnology plays a central role. Using self-assembled magnetic artificial cilia as an example, this presentation will discuss how systems engineering concepts apply to nanotechnology.

8373-46, Session 9

Nano-infusion: a new technology platform

T. G. Vargo, Integument Technologies, Inc. (United States)

Current research in the field of nanotechnology and the fabrication of polymeric composites is often complicated by the inability to obtain well-dispersed nano-particles within polymeric matrices. In general, these methods require that nanoparticles be protected by organic ligands that affect many of the properties inherent to unprotected nanoparticles (e.g., catalytic activity). In addition, the field of nanotechnology has recently come under both Governmental and Legal scrutiny regarding handling, shipping and use of nanoparticles with implications that will govern future development of new materials using nanoparticles. This presentation will describe a new “Polymer Platform Technology” for directly and permanently assembling “in-situ” metal and metal oxide nano-particles as well as interpenetrating networks of functional organics within polymeric materials.

By utilizing the inherent free volume contained in a fully cured organic polymer our laboratories have demonstrated the ability to grow metal and metal oxide nanoparticles that can be homogenously dispersed or controllably situated in any region within a polymeric matrix. In addition, this method provides fine control over nanoparticle sizes (and size distribution) down to several nanometers.

To date our nano-polymer composites have been used to demonstrate:

1. Controlled optical absorbance and reflectance properties in polymers
2. Controlled adhesion or foul release surface properties
3. Surface and bulk chelation of catalysts, dyes, anti-microbials, and sensor recognition elements

In conclusion, this process produces novel nano-metal/organic composites that exhibit a variety of unique chemical, biochemical, optical, and electrical characteristics that make them commercially attractive for many technological applications.

8373-47, Session 9

Electrofluidic systems for contrast management

K. J. Rebello, J. Maranchi, J. Tiffany, C. Brown, A. Maisano, The Johns Hopkins Univ. Applied Physics Lab. (United States); M. Hagedon, J. C. Heikenfeld, Univ. of Cincinnati (United States)

Operating in dynamic lighting conditions and in greatly varying backgrounds is challenging. Current paints and state-of-the-art passive adaptive coatings (e.g. photochromics) are not suitable for multi-environment situations. A semi-active, low power, skin is needed that can adapt its reflective properties based on the background environment to minimize contrast through the development and incorporation of suitable pigment materials. Electrofluidic skins are a reflective display technology for electronic ink and paper applications. The technology is similar to that in E Ink but makes use of MEMS based microfluidic strutures, instead of simple black and white ink microcapsules dispersed in clear oil. Electrofluidic skin's low power operation and fast switching speeds (<100 ms) are an improvement over current state-of-the-art contrast management technologies. We report on a three dimensional microfluidic display which utilizes diffuse pigment dispersion inks to change the contrast of the underlying substrate from 5.8% to 100%. Voltage is applied and an electromechanical pressure is used to pull a pigment dispersion based ink from a hydrophobic coated reservoir into a hydrophobic coated surface channel. When no voltage is applied the Young Laplace pressure pushes the pigment dispersion ink back down into the reservoir. This allows the pixel to switch from the on and off state by balancing the two pressures. Taking a systems engineering approach from the beginning of development has enabled the technology to be integrated into larger systems.

8373-48, Session 10

Heterogeneous integration of semiconductor materials: basic issues, current progress, and future prospects

J. M. Woodall, Purdue Univ. (United States)

The world's most favorite IC semiconductor material, silicon, cannot do everything we want a semiconductor material to do. However, for this discussion, the fact that Si wafers are of high quality, big and cheap is of great interest.

This is important for at least two reasons. First, nearly all of the electronic and photonic compound semiconductor devices that comprise the current $20 billion per year market are fabricated on substrates that are either very expensive or non-optimal for the epitaxy required to realize the device or an IC of interest.

A second reason is the integration of new functionality to current Si technology. Clearly, if many of the current photonic applications already realized in current compound semiconductor technology could be integrated into Si technology, some of the herculean efforts to continue following Moore's Law (including trying to do it via nanotechnology) could be mitigated.

The goal of this presentation is to examine some of the basic materials science issues involved with heterogeneous integration of semiconductor materials. These include those applications in which the active device region requires a high degree of crystal perfection and those that do not. We will focus on epitaxy issues at the hetero-interface, heterovalent versus homovalent epigrowth, and dislocation dynamics. Next we will briefly summarize some notable historical successes, followed by examples of current successful approaches including the materials science concepts used to achieve the results. Finally, we will examine the challenges that need to be solved in order continue making future progress.

8373-49, Session 10

Metamaterial sensors for infrared detection of molecular monolayers

E. Cubukcu, Univ. of Pennsylvania (United States)

Surface enhanced vibrational spectroscopy has been a topic of interest for interdisciplinary research owing to its ability to amplify molecular scattering cross sections through localized surface plasmon resonance. Surface enhanced Raman spectroscopy (SERS) and surface enhanced infrared absorption spectroscopy (SEIRA) are commonly employed techniques in which the minimum detection limit is determined by the strength of local fields around the metallic nanostructures. We report a novel surface enhanced molecular detection technique with zeptomole sensitivity per element that relies on resonant coupling of plasmonic modes of split ring resonators and infrared vibrational modes of a self-assembled monolayer of octadecanthiol (ODT) molecules. Large near-field enhancements at the gap of split ring resonators allow for this resonant coupling when the molecular absorption peaks overlap spectrally with the plasmonic resonance. A nanofabricated array of SRRs is coated with a monolayer of ODT. Absorption by molecules in the nanoscale gap modifies the SRR resonance spectrum upon interaction with the enhanced near-field in the gap. This effect manifests itself in the far-field transmission spectrum allowing us to detect the ODT molecules using far-field microscopy techniques. Our approach differs from previous plasmonic sensing schemes that rely on the local index change. This technique's ability to provide spectral fingerprint information along with its extremely low detection limit offer many possibilities in future infrared vibrational spectroscopy on the nanoscale.

8373-50, Session 10

Lensfree on-chip microscopy and tomography

A. Ozcan, Univ. of California, Los Angeles (United States)

Computational microscopic imaging modalities are becoming powerful due to rapidly improving performance of opto-electronic components (e.g., CCD and CMOS sensor-arrays), computers and image reconstruction algorithms. As a result of these advances, today we have unique opportunities to create new digital imaging platforms that significantly improve our micro-analysis toolset in terms of e.g., cost, compactness and throughput.

As part of this broad research theme, our research group at UCLA has recently created various lensfree on-chip imaging modalities including partially-coherent lensless holographic microscopy and tomography for field-use, cell-phone microscopy for telemedicine applications, and lensfree fluorescent imaging over an ultra-wide field-of-view using compressive sampling.

In this presentation, we will review the basic principles of these emerging computational microscopy techniques and demonstrate their applications to e.g., high-throughput imaging and counting of blood cells, monitoring of HIV+ patients (through CD4+ T cell counting) and detection of waterborne parasites (e.g., Giardia Lamblia and Cryptosporidium Parvum) toward water quality monitoring. In addition to these, we will also discuss lensfree implementations of various other on-chip microscopy modalities such as pixel super-resolution imaging, holographic opto-fluidic microscopy and tomography. And finally, we will discuss lensfree on-chip imaging of fluorescently labeled cells over an ultra-wide field-of-view of >8-10 cm2, which could be especially important for rare cell analysis applications such as detection of circulating tumor cells in whole blood or for high-throughput screening of DNA/protein micro-arrays.

These recent developments could enable new microscopic imaging tools that are especially useful for telemedicine and high-throughput biomedical imaging applications in resource-limited and remote locations.

8373-51, Session 10

Printed assembly of micro/nanostructured semiconductor materials for photovoltaics and optoelectronics

J. Yoon, The Univ. of Southern California (United States)

Unconventional approaches to exploit established materials in photovoltaics and optoelectronics can create novel engineering opportunities, device functionalities, and cost structures, each with potential value in different technological applications. Here, I will present an overview of materials and integration strategies that involve a large collection of micro/nanostructured inorganic semiconductor materials including silicon and gallium arsenide based compound semiconductors that are derived from bulk, wafer-based source materials through processes of anisotropic wet chemical etching, epitaxial liftoff, or others. Techniques of deterministic assembly offered a practical means to manipulate ultrathin, micro/nanoscale building blocks in a massively parallel manner, thereby enabling device- and module-level integration on various classes of foreign substrates with advantages in areal coverage, format, and cost-effectiveness that would be difficult or impossible with traditional wafer-based technologies.

8373-52, Session 11

Design and development of a revolutionary VTOL micro-air vehicle: the cyclocopter

M. Benedict, I. Chopra, Univ. of Maryland, College Park (United States)

The cyclocopter or a cycloidal-rotor aircraft is a revolutionary flying concept which has not been systematically studied in the past. One of the biggest advantages of the cycloidal-rotor (cyclorotor) is the fact that all the spanwise elements of the blade operate at the same aerodynamic conditions. This allows the blade properties of all the elements to be set to achieve optimum efficiency. Our studies have shown that an optimized cyclorotor can have higher aerodynamic efficiency than a conventional rotor of the same scale. As the thrust vector of a cyclorotor can be instantaneously set to any direction perpendicular to the rotational axis, the concept may also have better maneuverability compared to a conventional rotor based MAV, which makes it ideal for highly constrained indoor operations. Even though there have been many attempts from various researchers to build cyclorotor-based aircrafts, none of them have been successful in building a stable flight-capable vehicle until recently, when an MAV-scale cyclocopter was successfully built and flight tested at the University of Maryland. This paper would discuss the design and development of this vehicle. The paper would also include the systematic experimental and computational studies that have been conducted at the University of Maryland on the cycloidal rotor concept over the past 5 years which has been the key to the success of this vehicle.

8373-53, Session 11

Millimeter-scale, piezoMEMS-enabled autonomous systems: system feasibility and mobility

J. S. Pulskamp, R. G. Polcawich, G. L. Smith, C. M. Kroninger, U.S. Army Research Lab. (United States)

The U.S. Army is investing in basic research relating to autonomous small scale robots. A collaborative technology alliance between the U.S. Army Research Laboratory (ARL) and four academic and industry led research centers is performing basic research pertaining to the mechanics, electronics, processing for autonomy, and system integration of such systems. Internal research within the Sensors & Electron Devices Directorate (SEDD) at ARL has focused on a subset of this “Microsystems” topic, targeting the development of millimeter-scale robots. For the past several years, ARL has been developing key enabling technologies for MEMS-based millimeter-scale robotic systems. The research is currently comprised of three major thrust areas including bio-inspired mm-scale-flight, ground mobility, and proprioception. This presentation will provide an analysis of system feasibility and potential military utility of such millimeter-scale systems. The presentation will also highlight ARLs research on piezoelectric MEMS enabled platform mobility. Micro fabricated wing structures driven by integrated two degree of freedom piezoelectric MEMS actuators have successfully demonstrated insect-like kinematic performance at similar wing beat frequencies (120 degree and 46 degree stroke and pitch amplitudes at 120 Hz). Aerodynamic lift has been demonstrated in tethered platforms with externally provided power and control. High performance PiezoMEMS flexural actuators are also being developed for ground mobile platforms.

8373-54, Session 11

Yaw feedback control of a bio-inspired flapping wing vehicle

G. Gremillion, J. S. Humbert, Univ. of Maryland, College Park (United States); P. D. Samuel, Daedalus Flight Systems, LLC (United States)

A 12 gram fly-inspired flapping wing micro air vehicle was stabilized in the yaw degree of freedom using insect-based wing kinematics for lift generation and control actuation. The vehicle is fully self-contained including a single-cell LiPo battery power source, a rotary motor and drive train, servo control actuation, and communications receiver. It is capable of generating sufficient thrust for out-of-ground-effect liftoff as demonstrated in tethered testing with further thrust for additional payload. The characteristic parameters of biological insect flapping flight are examined, such as functional separation of the musculature and small kinematic variations. This musculature is separated into power and actuation systems, which is simulated on the vehicle by a rotary drive motor, with transmission system, and wing hinge servos, respectively. The variation of wing kinematics is used to produce small aerodynamic perturbations that accumulate over several wing strokes to form significant shifts in the center of lift to induce body moments. An external motion capture system was used to measure the vehicle heading state, allowing for minimal impact on vehicle payload and offboard processing. Proportional-integral-derivative control was applied to the vehicle heading states for feedback control to an insect-based parameter of the wing kinematics, differential stroke plane tilt. This parameter describes the rotation, in opposing directions, of the planes in which the right and left wings flap, inducing a yaw moment by tilting the right and left wing lift vectors. Tracking of a desired heading trajectory using this biologically-inspired wing kinematic actuation is successfully demonstrated.

8373-55, Session 11

Maneuverability and mobility in palm-sized, legged robots

N. J. Kohut, P. Birkmeyer, K. C. Peterson, A. O. Pullin, R. S. Fearing, Univ. of California, Berkeley (United States)

Palm sized legged robots show promise for military and civilian applications, including exploration of hazardous or difficult to reach places, search and rescue, espionage, and battlefield reconnaissance. However, they also face many technical obstacles, including- but not limited to- actuator performance, weight constraints, processing power, and power density. This paper presents an overview of several robots from the Biomimetic Millisystems Laboratory at UC Berkeley, including the OctoRoACH, a steerable, running legged robot capable of basic navigation and equipped with a camera and active tail; CLASH, a dynamic climbing robot; and BOLT, a hybrid crawling and flying robot. The paper also discusses, and presents some preliminary solutions to, the technical obstacles listed above plus issues such as robustness to unstructured environments, limited sensing and communication bandwidths, and system integration.

8373-56, Session 11

Challenges for micro-scale, flapping-wing, micro air vehicles

R. J. Wood, B. Finio, M. Karpelson, N. O. Perez Arancibia, P. Sreetharan, J. P. Whitney, Harvard Univ. (United States)

As the characteristic size of a flying robot decreases, the challenges for successful flight revert to basic questions of fabrication, actuation,

fluid mechanics, stabilization, and power - whereas such questions have in general been answered for larger aircraft. When developing a flying robot on the scale of a common housefly, all hardware must be developed from scratch as there is nothing "off-the-shelf" which can be used for mechanisms, sensors, or computation that would satisfy the extreme mass and power limitations. This technology void also applies to techniques available for fabrication and assembly of the aeromechanical components: the scale and complexity of the mechanical features requires new ways to design and prototype at scales between macro and MEMS, but with rich topologies and material choices one would expect in designing human-scale vehicles. With these challenges in mind, this talk will present progress in the essential technologies for insect-scale robots.

8373-57, Session 12

Biologically inspired, haltere, angular-rate sensors for micro-autonomous systems

G. L. Smith, W. D. Nothwang, B. E. Schuster, S. S. Bedair, C. D. Meyer, J. S. Pulskamp, R. G. Polcawich, U.S. Army Research Lab. (United States)

The paper details the design, fabrication and testing of a biologically inspired, low-power, two axis, angular rate sensor (ARS) to be integrated into micro-robotic aerial platforms. This MEMS enabled ARS maximizes the sensitivity to rotational rate (roll-pitch or yaw). The motivation of this work is the monolithic integration of ARS with other thin-film piezoelectric actuators and sensors enabling proprioceptive control of mm-scale and larger robotic platforms. A rate sensor is one of three critical sensors necessary to enable autonomous flight in micro-robotics. Insects such as the Drosophila flies achieve accurate angular rate information using an oscillating pendulum structure, called a haltere, that sits just behind their wings. The insects measure the resultant, Coriolis forces orthogonal to oscillations, caused by the angular rates with sensors at the base of the pendulum. Inspired by the insect sensors, we are exploring mechanisms to create a MEMS-based pendulum structure that is both actuated and sensed by thin-film piezoelectrics (lead zirconate titanate). Traditional, packaged rate sensors do not possess compatible size, weight and power (SWaP) to be practical for mm-scale, thus requiring an integrated approach. Modeling and testing indicates a system that is inherently sensitive to the Coriolis forces caused by changes in angular rate. Scale studies and modal analysis were completed to guide the MEMS-level snesor development. MEMS-based haltere have been fabricated as individual die and in coupled arrays. Understanding the coupling mechanisms between multiple haltere will enable triaxial-sensitivity at lower SWaP and thus will contribute to UAVs at an unprecedented scale.

8373-58, Session 12

Hair-based sensors for micro-autonomous systems

M. M. Sadeghi, R. L. Peterson, K. Najafi, Univ. of Michigan (United States)

We seek to harness microelectromechanical systems (MEMS) technologies to build biomimetic devices for low-power, high-performance, robust sensors and actuators on micro-autonomous robot platforms. Hair is used abundantly in nature for a variety of functions including balance and inertial sensing, flow sensing and aerodynamic (air foil) control, tactile and touch sensing, insulation and temperature control, particle filtering, and gas/chemical sensing. Biological hairs, which are typically characterized by large surface/volume ratios and mechanical amplification of movement, can be distributed in large numbers over large areas providing unprecedented sensitivity, redundancy, and stability (robustness). Local neural transduction allows for space- and power-efficient signal processing. Moreover, by varying the hair structure and transduction mechanism, the basic hair form can be used for a wide diversity of functions. This talk will explore the potential of hair-like sensors and actuators made through microfabrication. Using a novel wafer-level, bubble-free liquid encapsulation technology, we make arrays of micro-hydraulic cells capable of electrostatic actuation and hydraulic amplification, which enables high force/high deflection actuation and extremely sensitive detection (sensing) at low power. By attachment of cilia (hair) to the micro-hydraulic cell, air flow sensors with excellent sensitivity (10 m/s) have been built. A second-generation design has significantly reduced the sensor response time. These sensors can be used for dynamic flight control of flying robots or for situational awareness in surveillance applications. The core biomimetic technologies developed are applicable to a broad range of sensors and actuators needed on micro-robots for military and civilian applications.

8373-59, Session 12

Gallium nitride micromechanical resonators for IR detection

M. Rais-Zadeh, Univ. of Michigan (United States)

This paper reports on a novel technology for low-noise un-cooled detection of infrared (IR) radiation using a combination of piezoelectric, pyroelectric and resonant effects. The architecture consists of a parallel array of high-Q gallium nitride (GaN) micro-mechanical resonators coated with an IR absorbing nanocomposite. The nanocomposite absorber converts the IR energy into heat with high efficiency. The generated heat causes a shift in frequency characteristic of GaN resonators because of pyroelectric and piezoelectric effects. IR detection is achieved by sensing the shift in the resonance frequency and amplitude of the exposed GaN resonator as compared to a reference resonator that is included in the array. This architecture offers improved signal to noise ratio compared with conventional pyroelectric detectors as the resonant effect reduces the background noise and improves sensitivity. GaN is chosen as the resonant material as it possesses high piezoelectric and pyroelectric coefficients and can be grown on silicon substrate for low-cost batch fabrication. A GaN sensor is demonstrated with Q of more than 10,000 at 120 MHz, exhibiting the highest performance reported for GaN resonators to-date. Measured results of the GaN IR detector prototype will be reported in the full paper.

8373-60, Session 12

Micromachined low-mass RF front-end for beam steering radar

M. Vahidpour, M. Moallem, J. R. East, K. Sarabandi, Univ. of Michigan (United States)

Sensors for autonomous small robotic platforms must be low mass, compact size and low power due to the limited space. For such applications, as the dimensions of the structures shrink, standard machining methods are not suitable because of low fabrication tolerances and high cost in assembly. Commonly, the structures show a high degree of fabrication complexity due to error in alignment, air gaps between conductive parts, poor metal contact, inaccuracy in patterning because of non-contact lithography, complex assemblies of various parts, and high number of steps needed for construction. However, micromachining offers high fabrication precision, provide easy fabrication and integration with active devices and hence are suitable for manufacturing high MMW and submillimeter-wave frequency structures. Therefore, a novel micromachining process is developed to fabricate a Y-band high resolution radar structure with a slot-fed patch array antenna. The radar employs waveguide and planar technologies for

passive and active components respectively. It includes WR-3 waveguide trenches, membrane-supported CPW, slot array and patch array. The complete structure does not incorporate any dielectric material and is fabricated on three separate silicon wafers to form the waveguide trenches, slot arrays and patch arrays. The process mainly uses silicon DRIE to accommodate both waveguide structures as well as membrane-supported CPW lines. A multi-step silicon DRIE is developed for the fabrication of CPW/waveguide transitions. The slots are suspended on a thin oxide/nitride/oxide membrane to form the top cover of the waveguide trench and the patches are suspended on a thin Parylene membrane. Gold thermocompression bonding and Parylene bonding are used to assemble different parts of the antenna. The processes result in a compact and light-weight radar with 5g weight and 4.5 cm 3.5 cm 1.5 mm.

8373-61, Session 12

A programmable palm-size gas analyzer for use in micro-autonomous systems

R. J. M. Gordenker, K. D. Wise, Univ. of Michigan (United States)

Gas analysis systems having small size, low power, and high selectivity are badly needed for defense (detection of explosives and chemical warfare agents), homeland security, health care, and environmental applications. This paper presents a miniature gas chromatography system having analysis times less than a minute and detection limits less than 1ppb. The valveless three-chip microfluidic system consists of a preconcentrator, separation column, and detector, all realized using silicon micromachining and anodic silicon-glass bonding technology. The preconcentrator adsorbs vapors from an air carrier onto a bed of Carbopack grains and is then heated from ambient to 250°C in less than a second to thermally desorb them into the separation column. The analytes progress through the 25-300cm-long column, emerging at the output separated in time to allow detection specificity. One or two columns are typically used, coated with non-polar (e.g., polydimethylsiloxane) and/or polar (polytrifluoropropylmethylsiloxane) stationary phases. Using 3m columns resolving 14,000 theoretical plates, the separation of over thirty analytes has been achieved. The chemi-resistive detector is based on a gold-thiol nanoparticle-based thin film. Swelling of the film when exposed to gases of interest causes the particle separation to change, changing the film resistance. The entire system is realized on three 10cm x 4cm x 0.3cm boards, implementing the fluidic system and heater/temperature-sensing circuitry, the programmable temperature-control power electronics, and microcomputer-based control, data-capture, and data-transmission circuitry. The system occupies less than 100cc, operates from a 14.4V battery, and is configured for use on autonomous robotic vehicles.

8373-62, Session 13

Armor nanomaterials: hype, facts, and future

M. C. Maher, Defense Advanced Research Projects Agency (United States)

Over the past two decades, nanotechnology has offered the promise of revolutionary performance improvements over existing armor materials. During that time there was substantial effort and resources put into developing the material technology and supporting theories without ever understanding the mechanisms driving armor performance. To date there is no definitive answer as to what material properties drive the system behavior of these functions at the high rate of a ballistic event and the dependent nature of the threat, making the adaptation of nanotechnology that much harder.

No matter what the platform, armor systems have several functions that they have to perform in order to function properly. In order to defeat a threat, armor systems are designed to: deform/deflect the threat; dissipate energy; and prevent residual debris penetration. When these functions are considered with respect to the material system and armor mechanism being utilized, nanotechnology has been shown to be effective means of improving performance.

When looking at the materials being used today, there are examples of nanotechnology making inroads into today's latest systems. Nano-particles are being used to manipulate grain boundaries in both metals and ceramics to tailor performance. Composite materials are utilizing nanotechnology to enhance basic material properties and enhance the system level behaviors to high rate events.

While the anticipated revolution never occurred, nanotechnology is beginning to be utilized as an enabler in the latest armor performance improvements.

8373-63, Session 13

Designer materials for a secure future

N. P. Daphalapurkar, K. T. Ramesh, The Johns Hopkins Univ. (United States)

Materials for armor applications are increasingly being required to be strong and light-weight to survive the dynamic loads, as a consequence of increasing threat levels. Mechanism based models that can assist in improved materials design will be the focus of my talk. As specific examples, we will examine the dynamic behavior of aluminum nitride and of nanostructured aluminum alloys. The dynamic behaviors of these materials will be discussed in terms of deformation mechanisms and failure processes. Insights from high strain rate experiments and atomistic simulations are used to develop fundamental analytical models which might eventually assist in the design of materials, through microstructural modeling, and consequently be able to tailor the macroscopic properties. Lastly, I will talk about technical challenges that currently hinder accelerated materials development.

8373-64, Session 13

Carbon nanotube composite armor

D. S. Lashmore, Nanocomp Technologies Inc. (United States)

Nanocomp has developed under partial sponsorship from the Army Natick laboratories the technology for fabrication of CNT sheets and CNT yarns. These CNT materials can be selected to be single wall, dual wall or multiwall and represents the first time that large format CNT materials have been available for ballistic testing. Progress in compositing ballistic armor for personal protection will be summarized along with progress in production of high strength CNT yarn. Progress has been made in development of CNT polyurethane composites which have demonstrated that, at least for 9 mm full metal jacketed military bullets, ability to stop projectiles at about half the areal density of currently used Kevlar based armor. A preliminary model of CNT composite behavior will also be described which in summary suggests that a multilayered armor system with deformable spacers and thin high density CNT layers will be more effective in stopping bullets than will homogeneous stiff armor of the same areal density. This theory will be presented and correlated with experimental data. In addition the sponsorship of Natick has enabled other applications of CNT material for personal body armor protection. These include fireproof EMI shielding of the vest, adding CNT based coaxial cables to connect electronic devices, and very high performance butterfly antennae. Progress in high strength yarns will also be reviewed. A scaled up system to accomplish this and at the same time enable signification yarn production utilizing a 6 inch diameter furnace and a very high speed spinning system is being fabricated by Nanocomp to support this program and will be described along with tensile and modulus data on CNT yarns. This system should, for the first time, enable direct measurements of ballistic behavior of body armor fabricated from CNT yarns. Samples of body armor and related products will be shown.

8373-65, Session 13

Multiscale modeling of high-strength fibers and fabrics

J. A. Thomas, M. Boyle, M. Shanaman, X. Calderon-Colon, E. LaBarre, J. Tiffany, M. Trexler, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Using a combination of electronic structure calculations, molecular dynamics simulations, and finite-element analysis, we examine the physical mechanisms governing the performance of high-strength fibers and fabrics over a variety of length scales. To begin, we use electronic structure calculations to examine the molecular structure of Kevlar polymers, and quantitatively compare the intramolecular interactions to the non-bonded intermolecular interactions. We then quantify the potential energy landscape between Kevlar polymers, and fit this data to a potential function for use in molecular dynamics simulations. From molecular dynamics simulations, we calculate the stiffness of individual Kevlar polymers and quantify the effects of polymer entanglement, defects, and voids on the stiffness and failure properties of Kevlar threads. This stiffness and failure data is then used in a finite-element model of a Kevlar fabric to predict its overall ballistic impact resistance. At each stage, we compare the simulation predictions to experimental measurement obtained from thread pull-out tests, yarn tensile tests, and ballistic impact tests.

The relentless miniaturization of engineering systems, combined with new techniques for controlling the structure of materials at the atomic and/or molecular level, necessitates the development of new modeling tools for predicting the performance of mechanical and material systems. Although applied here to personal protection equipment, the multiscale modeling approach used in this work is general. Multiscale modeling can be used to optimize systems across a variety of length scales, and presents an approach for designing systems/materials with tailored properties at the molecular, microscopic, and macroscopic levels.

8373-66, Session 13

Strategic maturation of technology and manufacturing readiness for nanomaterials production

R. H. Carter, E. Chin, U.S. Army Research Lab. (United States)

To facilitate the transition of emerging materials technologies, in particular nano-materials, a strategically coordinated effort to advance both the technology readiness and manufacturing readiness levels is needed. Short term transitions are realized for materials readily adapted into existing industrial production infrastructure with capabilities to meet market needs. Longer developmental cycles are necessary if processing or manufacturing methodologies are not available beyond lab scale demonstration. Three categories of technology development based on the Technology Readiness Level/Manufacturing Readiness Level (TRL/MRL) associated with primary and secondary processing maturities to produce nano-materials are identified. This analysis of materials development will illustrate the need to synchronize the nano-technology with manufacturing technology over short and long term development efforts to increase the probability of successful transition. This also illustrates a strategic balanced portfolio for planned transitions, unforeseen discoveries and requirements. Selected examples of planned transition of in-progress research in nano-composites, ceramics and polymers at the Army Research Laboratory will be given.

8373-67, Session 14

Emerging nanomaterials for gamma and neutron radiation detection

M. Osinski, The Univ. of New Mexico (United States)

Gamma and neutron radiation detectors are becoming increasingly important for the nuclear forensic analysis, homeland security against terrorist threats, long term monitoring of nuclear waste storage sites, personnel protection, nuclear accident prevention, and environmental safety. Nanomaterials have attracted tremendous interest over the last few years for a wide range of biomedical, biochemical sensing, and optoelectronic applications. So far, however, their potential for nuclear radiation detection remains to be revealed. In this paper, the current status of the emerging nanomaterials for gamma and neutron detection applications is reviewed. Recent results on a variety of scintillating nanocrystals and nanocomposites are presented.

8373-68, Session 14

SnO2-based memristors and the potential synergies of integrating memristors with MEMS

D. Zubia, S. F. Almeida, J. A. Cervantes, A. Talukdar, E. W. MacDonald, The Univ. of Texas at El Paso (United States); J. Mireles, Jr., Univ. Autónoma de Ciudad Juarez (Mexico)

Memristors, usually in the form metal/metal-oxide/metal, have attracted much attention due to their potential application for non-volatile memory. Their simple structure and ease of fabrication make them good candidates for dense memory with projections of 22 terabytes per wafer. Excellent switching times of ~10 ns, memory endurance of >109 cycles, and extrapolated retention times of >10 yrs have been reported. Interestingly, memristors use the migration of ions to change their resistance in response to charge flow, and can therefore measure and remember the amount of current that has flowed. This is similar to many MEMS devices in which the motion of mass is an operating principle of the device. Memristors are also similar to MEMS in the sense that they can both be resistant to radiation effects. Memristors are radiation tolerant since information is stored as a structural change and not as electronic charge. Functionally, a MEMS device's sensitivity to radiation is concomitant to the role that the dielectric layers play in the function of the device. This is due to radiation-induced trapped charge in the dielectrics which can alter device performance and in extreme cases cause failure. Although different material systems have been investigated for memristors, SnO2 has received little attention even though it demonstrates excellent electronic properties and a high resistance to displacement damage from radiation due to a large Frenkel defect energy (7 eV) compared its bandgap (3.6 eV). This talk discusses recent research on SnO2-based memristors and the potential synergies of integrating memristors with MEMS.

8373-69, Session 14

Engineered nanoparticles for improved vasoactive intestinal peptide (VIP) modulation of the immune response

D. Pozo Perez, Ctr. Andaluz de Biologia Molecular y Medicina Regenerativa (Spain) and Univ. de Málaga (Spain); S. Lopez-Enriquez, R. Klippstein, Ctr. Andaluz de Biologia Molecular y Medicina Regenerativa (Spain)

Nanotechnology can address key bottlenecks hindering successful bench to bedside translation of recent research in the development of neuropeptide-based drugs. This is the case for vasoactive intestinal peptide (VIP), where sustained interest in its therapeutic applications needs to devise new methodologies to improve its drugability or to convey innovation to diagnostics to identify cells that result from conditions such as carcinoid metastasis in which VPAC receptors are involved. Here we present our results covering the chemical synthesis and functional characterisation of VIP Au/Ag nanoparticles, the protective effects on protease-based degradation, and the specific target to tumor cells or dendritic cells as an approach to cell therapy by using VIP-

nanoliposomes.

8373-70, Session 14

Microsystems: technology enabler for ...

M. Okandan, Sandia National Labs. (United States)

The microelectronics revolution has provided incredible improvements in our daily lives. With the immense investment in microelectronics technology that enabled this revolution, many new applications are being addressed that might have been initially envisioned. Some of these applications are a direct evolution of the microelectronics fabrication techniques, such as physical sensors (pressure, acceleration, light, etc.). Other areas, such as chemical sensors and neural prosthesis, have been associated with microfabrication, but are different enough that their evolution has taken a different path. This presentation will highlight some of these varied application areas, and provide suggestions and examples on some of the new areas where the microelectronics technology base is being leveraged : renewable energy and novel computational architectures that emulate neural systems.

8373-71, Session 14

Nanogold as NEMS platform: past, present, and future

V. M. Castaño, Univ. Nacional Autónoma de México (Mexico)

Gold has been a biomedical material since ancient times. We call review the historical uses of gold, in different forms as well as the properties of this metal, which make it very attractive for MEMS and NEMS applications. In particular, will discuss the synthesis and physic-chemical characteristics of nano particles of gold, emphasizing the role of surface modification, which enables the nano gold to act as a true nano reactor or a nano platform to develop various functions at the nanoscale. Finally, will describe the use of nano gold for drug targeting and disease detection.

8373-92, Poster Session

Very sensitive nanocomposite UV photodetector with performance superior to inorganic photodetectors

J. Huang, Univ. of Nebraska-Lincoln (United States)

Ultraviolet photodetectors (UV-PDs) are under investigation for many applications in the medical, industrial, communication, defense, and research fields. Today, semiconductor solid UV-PDs are generally made of single crystalline silicon, silicon carbide (SiC) or gallium nitride (GaN) p-n junction photodiodes. However, these single crystalline PDs have limitations that make them unsuitable for many applications due to their high cost, low quantum efficiency of less than 40% (responsivity of less than 0.2 ampere per watt (A/W)), and demand of cooling for very weak light sensing. Solution processed PDs based on organic- and/or nano-materials represent a direction to significantly reduce the cost but always leading to a lower performance than inorganic counterpart. Here, we report a solution processed UV-PD with a nanocomposite active layer composed of zinc oxide (ZnO) nanoparticles (NPs) blended with semiconducting polymers which significantly outperforms the inorganic PDs. This class of PDs shows a self-adaptive transition from a Schottky contact in the dark to ohmic contact under irradiation, and a huge internal gain of 4,080 enabled by the trap-controlled charge injection. The combination of low dark current of the Schottky diode and high responsivity of 1,165 A/W under a relatively low bias below ten volts leads to a very high detectivity of 1.9 × 1015 Jones at 340 nm at room temperature, 2-3 orders of magnitude higher than that of the Si or GaN UV-PDs.

8373-93, Poster Session

A self-calibrating, bi-axial piezoelectric MEMS tilt sensor

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The direct piezoelectric effect that crystalline materials exhibit, either naturally or synthetically, constitutes the foundation for the development of many sensors such as tactile, pressure and acceleration. Typically, when a piezo-based sensor is developed, its output is modeled as a direct function of its geometric, electro-mechanical and piezoelectric properties. This means that an accurate representation of the sensor output requires an accurate knowledge of its characteristics. In piezoelectric MEMS applications however, such information is either not available, or is provided in the form of approximate values. These values are further susceptible to the effect of external stimuli, such as temperature, or to intrinsic unquantifiable deformations resulting from fabrication imperfections. To address these issues, this paper proposes a new methodology that models the direct piezoelectric effect as a function of genetic data provided a priori about the operation of a piezo-system. The resulting model is shown to be independent of any system-specific characteristics or any external stimuli. The impact that these parameters exhibit on the output of the piezoelectric layer is carried implicitly by the genetic data which is generated through calibration. The validity of the proposed model is demonstrated through simulations performed on a new piezoelectric device for dual-axis tilt measurement. These results show a considerable accuracy under variations in the operating conditions, such as temperature and gravity.

8373-95, Poster Session

Lens-free, near-infrared (NIR) imaging using structured substrates and compressive sensing

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We introduce the use of sub-wavelength structured surfaces along with lensfree computational imaging to increase the effective pixel-density of an infrared sensor-array. In this lensfree technique, an incoherent infrared object-field is directly projected onto a structured metallic film that is composed of a set of sub-wavelength apertures. The transmitted-light, after being modulated by these on-chip structures, diffracts over a short distance (e.g., < 1 mm) to be sampled by a sensor-array without the use of any lenses or other optical components. This detected diffraction pattern then permits rapid reconstruction of the infrared object distribution on the chip at the sub-pixel level using compressive sampling/sensing algorithms.

The sub-wavelength on-chip apertures in this technique are designed such that the diffraction pattern of a point-source located on any part of this structured chip casts a unique two-dimensional diffraction pattern on the sensor-array. Therefore a given structured substrate is initially characterized by scanning a point-source across the fabricated chip area to capture a set of lensfree calibration diffraction images. This calibration process needs to be done only once, and any arbitrary incoherent object can be represented as a weighted linear super-position of these lensfree calibration frames. Therefore these acquired calibration frames enable reconstruction of an arbitrary object distribution impinging on the structured chip using the measurement of its modulated lensfree diffraction pattern sampled by an opto-electronic sensor-array. We experimentally demonstrate the feasibility of this approach at both visible and near-infrared wavelengths, increasing the pixel-density of the sensor-array by ~9 fold (i.e., 3x3 in x-y).

8373-97, Poster Session

Reliable SERS substrates by controlled assembly of nanoparticles

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Reliable SERS-based chemical sensors are possible with the proper design of nanostructures on the enhancing surface. This talk will present techniques for the immobilization and assembly of metal nanoparticles on substrates and the analysis of the reliability of these techniques with respect to producing effective SERS-based sensors. The fabrication methods that will be addressed are: "vertical deposition" of nanoparticles on topography-textured substrates using capillary forces; electrophoretic deposition of nanoparticles in templates prepared by e-beam lithography; and templating through electrostatic interactions between nanoparticles and self-assembly block-copolymers. Each method results in a tunable arrangement of plasmonic nanoparticles that can be optimize to obtain the maximum SERS enhancement factor. Our studies address both large area substrates and localized nanoscale structures. Notably, the use of self-assembly makes our approach economically favorable.

The fabrication techniques are evaluated through the distribution of the enhancement factor measured in hundreds of sensing sites. Relationships between efficiency, geometry of aggregation and plasmon resonances will be presented. We employ two strategies for tuning the plasmon resonance frequency: (1) by controlling the inter-particle distance between metal nanoparticles in a two-dimensional lattice, and (2) by controlling the number of nanoparticles in isolated clusters. With the first approach we demonstrate that the largest SERS enhancement is obtained when the resonance frequency is close to the incident laser frequency. With the second approach we determine the dependence of the SERS enhancement factor distribution on the size of the self-assembly clusters. We show that more than two nanoparticles are often required to optimize the SERS-based sensors.

8373-100, Poster Session

IR microscopy using external-cavity, quantum-cascade lasers

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Infrared (IR) microscopy has shown itself to be an important tool by providing spectroscopic and chemical analysis in areas as diverse as analyzing surface defects in manufacturing to tissue diagnostics at the molecular level. To date, the main tool for performing IR microscopy has been the Fourier Transform Infrared (FTIR) microscope, but these have been limited by the poor optical quality of the incandescent light source. Recent work has used synchrotron sources to significantly increase the performance of IR microscopy, but these sources are limited in applicability due to their cost and complexity. The development of broadly tunable, external cavity quantum cascade lasers (EC-QCLs) has created an ideal light source for IR microscopy.

Initial results were obtained by coupling an EC-QCL to a commercially available FTIR microscope. Spectral performance and coherence effects were determined by performing scans for different sample materials. Advantages of the EC-QCL based spectra included higher spatial resolution (10 µm vs. 25 µm), higher spectral resolution (1 cm-1 compared to 4 cm-1), and less averaging time (5 sec vs. 1 min).

The laser based IR microscope was further improved by coupling to a micro-bolometer FPA detector. Images of approximately 2 mm by 2 mm were obtained for both reference samples and reticles to determine the performance, and results compared well to synchrotron based IR microscopes. EC-QCL based imaging microscopes stand ready to rival the performance of state-of-the art IR microscopes for a fraction of the cost and complexity.

8373-101, Poster Session

Relation between charge on free electrodes and the response of electrostatic MEMS actuators and sensors

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Stability is an important factor in the study of electrostatic MEMS switches and sensors. Their response is significantly improved by either applying a large dc bias or by depositing a prescribed value of charge on the floating electrodes. This charge is related to the pull-in voltages. Measurement of charge without causing loading is recommended; so instead of incorporating any field operated transistor circuitry for this purpose, methods are developed to relate the charge magnitude to the dynamical response of the actuators. Elata et al. developed efficient and reliable ways of charge monitoring without causing loading to the device. These methods rely on energy of the system instead of performing integration in the time domain. Based on their work, this paper examines the alterations in the dynamic response of actuators. The positive and negative pull-in voltages in the voltage displacement plane are symmetrically located with respect to charge on the floating electrode. This fact is exploited to carry out indirect charge measurement from the average of the two pull-in values. A regression scheme is proposed that predicts the charge decay based on limited measurements on the response of the actuators.

8373-103, Poster Session

Ultrafast bangap photonics and low-observable problem

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Ultrafast Bandgap Photonics is discussed as an alternative technology for laser-induced low observability. Ultra-fast laser is capable of providing fundamentally different type of low observables -LO that may not require fundamental changes in platform design and reduction in its efficiency as it happens for conventional LO. Foundation of ultra-fast laser LO technology is its ability to remotely alter IR detector characteristics in a way that prevents target detection. As a matter of fact that technology may be effectively used in Directional IR Counter Measures-IRCM as well and that may greatly reduce vulnerability and efficiency of EW. In this paper, we will consider the effects caused by relatively low energy per pulse ultra-fast and, to some extent, fast lasers.

8373-104, Poster Session

Bragg reflectors for large optical aperture MEMS Fabry-Perot interferometers

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Tuneable MEMS Fabry-Perot interferometers (FPIs) are suitable for realizing miniature spectrometers, which can be utilized for detection of gases (in the IR range) or for biological analysis in the visible-NIR range. For single-point spectroscopic measurements, the optical aperture size of 1 - 2 mm has been sufficient to obtain desired measurement sensitivity. Imaging spectrometers for medical- and space applications however require larger FPI optical aperture size for high resolution measurement performance. This paper presents the fabrication of large-aperture low-pressure chemical-vapour deposited (LPCVD) Bragg reflectors utilizing low-stress polysilicon and silicon nitride λ/4-thin film stacks. These structures can function as the upper mirror in a MEMS FPI device. High aspect-ratio mirror membranes were successfully released for 5 - 10 mm diameter range by sacrificial SiO_2 etching in HF vapour. Optical simulations are presented for the Bragg reflector test structures designed

for FPIs operating in the NIR range and the properties such as release yield and mechanical stability of the released LPCVD deposited polySi-SiN mirror membranes are compared with similar released atomic layer deposited (ALD) Al2O3-TiO2 λ/4-thin film mirror stacks. The realization of these Bragg reflector structures is the first step in the process integration of large-aperture MEMS FPI for miniature NIR imaging spectrometers, which can be applied to a variety of applications ranging from medical imaging and diagnostics to space- and environmental monitoring instrumentation.

8373-105, Poster Session

Sensitive detection of multivalent ions via DNA bridge: toward SWNT-based optical sensors

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The method is based on the physics of interaction of multivalent ions (Tb3+, Eu3+, Al3+, Ca2+) with SWNTs wrapped with the single strand (ss) DNA, being ionized/negatively charged in the aqueous solution. Using time-resolved photoluminescence (PL) we found positive correlation (attraction) of Tb and Eu to the DNA/SWNT complexes. We speculate that Manning condensation of the multivalent ions on the SWNT/DNA surface happens thereby significantly reducing their spacing. By altering the complexes' geometry one makes the near field energy transfer between the ions and the SWNT possible.

In the case of lanthanide salts we observed a strong dependence of the SWNT near-infrared emission intensity on the lanthanide ion concentration. The lanthanide ion adsorption on the SWNT should lead to an enhanced SWNT emission in NIR range due to the energy transfer from excited ions. At the same time, resonant excitation of the SWNT changes in the presence of lanthanide ions, possibly due to the DNA ordering. The PL dynamics indicates that the binding of Tb/ Eu ions to the ssDNA/SWNT is followed by two competing processes: (a) a SWNT PL enhancement due to the resonant energy transfer and/or other near-field interactions, and (b) the SWNT agglomeration followed by the PL quenching. In case of Al3+ and Ca2+ similar processes take place, allowing multivalent ion detection.

This sensing mechanism is advantageous by showing high sensitivity (20uM ion concentration) and capability to trace the kinetics of the ions condensation.

8373-106, Poster Session

Near-field thermal properties of nanocarbons

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Various forms of nano-carbon materials, such as graphene, nanotubes, nanotube forests, are currently explored for thermal sensor applications. Being advantageous for light weight, chemical and mechanical durability, high thermal conductance, they still present a challenge from a scientific point of view: our classical expectations from the thermal physics of the bulk matter are not always met, often postponing the device engineering. On the other side, it is the combination of unusual and non-classical properties of nanomaterials which we need to know and implement to enhance current technologies.

We present a model explaining near-field thermal interfacial properties of various nano-carbons in a unified manner. The common physics of the near-field heat transport in the low-dimensional structures is unveiled and expressed in terms of the Quantum Electrodynamics Kapitsa conductance. We present the numerical results as well as analytical expressions for the limiting cases. The universal formula for the QED Kapitsa conductance is developed which contains only the materials properties of the thermal interface, such as graphene/nanotube Fermi velocity, frequency and strength of the near-field modes of the substrate, besides the physical fundamental constants. We derive the temperature dependence of the QED Kapitsa conductance. For non-constant density of states of the nano-carbon material, such as in the case of graphene (linear DOS) or a semiconductor nanotube (singular DOS), the Kapitsa conductance depends on the chemical potential which potentially allows the heat rectification to be observed.

8373-107, Poster Session

Sensing trace amounts of Nitroaromatic explosives using nanowire-nanocluster hybrids

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Chemical sensors for trace amounts of nitroaromatic-explosives, have gained importance due to the increased threat of explosive attacks worldwide. Detecting traces of explosives is a challenging task because of the low vapor pressures of most explosives. Nanowire-nanocluster hybrid sensors were realized by functionalizing gallium nitride nanowires with titanium dioxide nanoclusters for selectively sensing aromatic and nitro-aromatic compounds. GaN nanowires with diameters of ~200 nm were grown using Molecular Beam Epitaxy. These nanowires were aligned on a nonconducting substrate and complete sensor structures were fabricated using standard microfabrication techniques. The TiO2 nanoclusters were deposited on the nanowires devices utilizing RF magnetron sputtering. The GaN/TiO2 nanowire-nanocluster hybrid devices use the photocatalytic properties of TiO2 to sense specific volatile organic compounds at ambient temperature. These sensors detected 0.5 ppb of trinitrotoluene with good selectivity against interfering compounds like dinitrotoluene. Even though the sensors did respond to xylene, ethyl benzene, benzene, toluene, and chlorobenzene for concentration levels as low as 50ppb, their response to the aromatics and nitro-aromatics is quite different. It is also worth mentioning that our devices are not sensitive to other classes of organic compounds like alcohols, ketones, aldehydes and amides. The sensitivity of 1 ppm of TNT is ~10% with response and recovery times of ~30 s. Efforts are underway to improve the sensitivity of the devices and to detect explosive vapors even at sub-ppt concentrations. These sensor devices were highly stable and were able to sense the analytes reliably with concentrations as high as few percents in air.

8373-108, Poster Session

Fabrication of vertically aligned GaN core-shell nanostructures for sensing applications

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Vertically aligned core-shell n-p nanostructures are technologically significant due to their potential applications in a variety of devices such as light-emitting diodes, laser diodes, photodetectors, and solar cells. Here, we report on development of a hybrid approach to produce arrays of vertically aligned GaN n-p core-shell structures. First, we fabricated nanoscale n-type GaN pillars by inductively coupled plasma (ICP) etching which were subsequently overgrown by p-type GaN shell using halide vapor phase epitaxy (HVPE) process. We will present results on the optimization of the ICP etching procedure, in particular ICP and radio frequency (RF) powers, to obtain GaN pillars with vertical and smooth sidewalls. Preliminary results on HVPE overgrowth and characterization of core-shell GaN pillars will be discussed as well. GaN thin films of thickness about 1µm used in this study were grown by

MOCVD technique on 4” n-Si(111) wafers. Ti/Ni etch masks containing features of various shapes and sizes ranging from 250 nm to 10 µm were fabricated on top of the GaN film using deep UV lithography and lift-off techniques. Then, the samples were ICP etched in a Cl2/N2/Ar (25:5:2) gas mixture under a pressure of 5 mTorr with varying ICP etching power and radio frequency (RF) power. The etching time 4 min and temperature 40 °C were kept fixed for all the samples. The overgrowth of GaN pillars was performed in a home-built horizontal HVPE reactor at 1020 °C and pressure 450 Torr using nitrogen and Cp2Mg as carrier gas and p-type dopant, respectively.

8373-109, Poster Session

Development of nanostructure-based antireflection coatings for EO/IR sensor applications

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EO/IR sensors are being developed for a variety of defense and commercial systems applications. These include UV, Visible, NIR, MWIR and LWIR Nanotechnology based Sensors. The conventional SWIR Sensors use InGaAs based IR Focal Plane Array (FPA) that operate in 1.0-1.8 micron region. Similarly, MWIR Sensors use InSb or HgCdTe based FPA that is sensitive in 3-5 micron region. More recently, there is effort underway to evaluate low cost SiGe visible and near infrared band that covers from 0.4 to 1.6 micron.

8373-110, Poster Session

IonCCD as an alternative pixelated anode for direct MCP readout in imaging and spectroscopy

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We report on the preliminary testing of a new position-sensitive detector (PSD) by combining a microchannel plate (MCP) and a charge-sensitive pixilated anode with a direct readout based on charge-coupled detector (CCD) technology, which will be referred to as IonCCD. This work exploits the recently discovered electron detection capability of the IonCCD, allowing it to be used directly behind an MCP. This MCP-IonCCD configuration potentially obviates the need for electro-optical ion detector systems (EOIDs), which typically feature a relatively difficult-to-implement 5-kV power source as well as a phosphorus screen behind the MCP for conversion of electrons to photons prior to signal generation in a photosensitive CCD. Thus, the new system (MCP-IonCCD) has the potential to be smaller, simpler, more robust, and more cost efficient than EOID-based technologies in many applications. The use of the IonCCD as direct MCP readout anode, as opposed to its direct use as an ion detector, will benefit from the instant three-to-four-order-of-magnitude gain of the MCP with virtually no additional noise. The signal/noise gain can be used for either sensitivity or speed enhancement of the detector. The speed enhancement may motivate the development of faster IonCCD readout speeds (currently at 2.7 ms) to achieve the 2 kHz frame rate for which the IonCCD chip was designed, a must for transient signal applications. The presented detector exhibits clear potential not only as a trace analysis detector in scan-free mass spectrometry and electron spectroscopy but also as a compact detector for photon and particle imaging applications.

8373-111, Poster Session

Multifrequency and broadband optical antennas

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Traditionally, light is controlled by optical components such as lenses, mirrors, and diffractive elements. However, there are many drawbacks for these conventional devices such as bulky size and suffering from the diffraction limits. In order to solve these problems, optical antennas have been proposed recently. It overcomes the constraints imposed by conventional optical devices, allowing unprecedented control of light-matter interactions within sub-wavelength volume. Up until now, almost all of the existing optical antennas can only operate at single fixed frequency. This has highlighted the need for designing optical antennas covering multiple working frequencies or broad frequency band to achieve more design and application flexibility. Motivated by this factor, in this paper, we propose to design and fabricate new optical antennas with engineered spectrum responses. Optical antennas with multi-frequency and broadband operations will be investigated for the first time. Specifically, we will investigate several optical antenna topologies to introduce multiple resonant peaks. Potential candidate designs include the stepped-junction nano-antenna, and the multiple-pair nano-dimer. Moreover, inspired by the wide-band antenna design concept developed in the microwave frequency range, broadband optical antennas will be investigated, which will further enable us to control light over broad spectrum. Finally, the proposed optical antennas will be fabricated through different methods such as electron beam lithography (EBL) and holographic lithography based method. It is expected that the proposed optical antennas will pave the way towards the development of multi-functional nano-devices, which are key components for realizing high performance bio/chemical sensing, imaging, photo-voltaics, and nano-manufacturing.

8373-112, Poster Session

High-resolution digital spectrometers-on-chip

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Digital planar holography (DPH) is a revolutionary approach for designing devices with the desired properties to control light. This concept was used to design a new class of ultra-miniaturized and high-resolution spectrometer-on-chip. The holograms involve millions of identical elements for which their positions encode the transfer function of the spectrometer [1]. Two types of spectrometers were developed using substrates of Si/SiO2/SiO2:Ge and Si/SiO2/Si3N4. Ge-doped silicon dioxide (~3% contrast) and silicon nitride(~35% contrast) films were used as a waveguidecore. DPH structures were written using electron beam lithography or nanoimprint lithography. Reactive ion etching was used to transfer the pattern into silicon dioxide or silicon nitride waveguide layers [2]. Devices have been demonstrated up to 1000 channels and a spectral resolution up to 4.105.

We report for the first time a novel type of Multi-Band Digital Optical Spectrometer-on-chip into SiO2GeX waveguide core. Spectrometers operate in four individual bandwidths within the visible range (477.2-478.0 nm, 528.8-529.9 nm, 586.4-587.7 nm, 628.9-630.4 nm) with 96 channels and a spectral resolution down to 0.0375 nm. For increasing the integral bandwidth, we developed spectrometers based on high contrast planar waveguides with Si3N4 core. 300 channels spectrometer with spectral spacing around 0.3nm/channel is demonstrated.

In conclusion, we have demonstrated two novel digital spectrometers

operating in visible range: 4-band 240-channel spectrometer with spectral resolution ~0.18 nm/channel and 300-channel broadband spectrometer with spectral resolution ~0.3 nm. In all devices the bandwidth, channel spacing, and spectral shape of individual channelsare in good agreement with simulations.These results confirm the potentialities of Digital Planar Holography for the design of integrated optical devices and pave the way for therealization of compact, application-specific, high resolution integrated spectrometers.

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8373-113, Poster Session

Selective immobilization of proteins on semiconductor nanowires and thin films for biosensor development

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Silicon, silicon carbide, and gallium nitride are attractive materials for chemi-/bio-sensing applications [1-3]. In order to enable thin film or nanowire (NW) based devices that utilize direct electronic sensing of biomolecules, one must develop an analyte-specific functionalization of the semiconductor surface and deduce mechanisms by which the functional and analyte molecules bind to the surface. This work presents a bioconjugation technique for the attachment of protein molecules to SiC thin films and to Si, SiC, and GaN NWs. Selective immobilization of the streptavidin (SA) protein on biotinylated surfaces of these semiconductors was studied and verified by a suite of surface characterization techniques.

To enable protein conjugation, the thin films and NWs were first functionalized with 3-aminopropyltriethoxysilane and subsequently biotinylated for enabling selective immobilization of the SA protein. SEM, TEM, AFM, XPS, ellipsometry, fluorescence microscopy, and contact angle measurements were utilized to study the thin film/NW surface after each functionalization step. On the SiC thin films, optimization of the APTES layer thickness was found to be critical for the subsequent steps: deposition of close to a monolayer of APTES was necessary for successful follow-up bioconjugation of biotin and SA, while thick polymerized APTES films resulted in irreproducible accumulation of biomolecules.

Selective SA attachment to Si, SiC, and GaN NWs was also demonstrated; further protocol optimization is in progress for developing more uniform coatings of organic layers on the NW surfaces. The experimental results reveal that the biotinylated thin films and NWs have the potential to be employed as a biosensing platform.

8373-72, Session 15

Target-specific sensing using SERS

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A bifunctional, adenosine-sensitive single-strand DNA aptamer was used to link 20 nm Au nanoparticles, thereby creating an analyte-controllable SERS hot spot in the junction between the particles. One of the nanoparticle was decorated with ABT, a Raman reporter molecule. In the presence of target analyte, the SERS intensity of ABT increased dramatically due to the aptamer's conformational change induced by its interaction with the target. Washing the sensor with buffer caused the SERS intensity and all details of its spectrum to revert to its pre-recognition-event levels, restoring the system's activity towards the analyte.

8373-73, Session 15

Standard method for characterizing SERS substrates

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We present the results of a three year collaboration between the US Army Edgewood Chemical Biological Center, and the US Army Research Laboratory-Aldelphi Laboratory Center on the assessments of various nano metallic surfaces developed for the Defense Advanced Research Programs Agency (DARPA) SERS Science and Technology Fundamentals Program. The primary role of the two Army labs was to develop the analytical and spectroscopic figures of merit to compare the sensitivity and reproducibility of the SERS substrates submitted by the program participants. We present the design of a protocol for evaluating dissimilar SERS active surfaces. We also introduce the use of receiver operating characteristic (ROC) curves to define an effective enhancement factor for substrate comparison.

8373-74, Session 15

Controlling the synthesis and assembly of silver nanocrystals for ultrasensitive detection by SERS

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Detecting toxic chemical or biological agents in small amounts requires a highly specific sensing technique, such as surface enhanced Raman spectroscopy (SERS). The controlled synthesis of metallic nanocrystals has provided a new class of substrates for more reliable and sensitive SERS applications. The nanocrystal shape plays a major role in designing SERS substrates which maximize the SERS enhancement factor (EF) of a molecule, and assembling nanocrystals into dimers can further amplify the EF, opening the door to the possibility of single molecule detection. Here, we present our recent work on the synthesis of silver nanocrystals and their assembly into dimers and other reliable techniques to form hot-spots with high EFs. These dimers demonstrate EFs as high as 1.0x10^8, at least 170 times higher than that of a single nanocrystal.

8373-75, Session 15

Evaluation of SERS substrates for chemical agent detection

S. R. Farquharson, Real-Time Analyzers, Inc. (United States)

One of the major challenges in Afghanistan is supplying US Military forces with sufficient water to conduct operations. One in five casualties is due to protecting fuel and water resupply lines. Consequently the use of indigenous water supplies to hydrate deployed forces plays a critical role. However, such water supplies are considered prime targets to effect a chemical or biological attack. There is a clear need for a portable analyzer capable of evaluating water supplies prior to use. To this end we have been investigating the use of a portable Raman analyzer and surface-enhanced Raman sampling systems. The rich molecular information provided by Raman scattering and the increased sensitivity provided by surface enhancement from silver or gold nanoparticles has been successfully demonstrated for biotechnological, environmental, homeland security, military, medical, and pharmaceutical applications. However, the exceptionally sensitivity provided by SERS is due to "hot spots", structures such as particle junctions that can provide as much as 10-orders of magnitude enhancement. Unfortunately, hotspots are not evenly distributed across substrates, which results in enhancements that cannot be quantitatively reproduced. Here we present analysis of uniformity for several SERS substrates using benzenethiol, bispyridylethylene, and methyl phosphonic acid, a major hydrolysis product of the nerve agents.

8373-76, Session 15

Nanowire-based surface-enhanced Raman spectroscopy (SERS) for chemical warfare simulants

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Hand-held instruments capable of spectroscopic identification of chemical warfare agents (CWA) would find extensive use in the field. Because CWA can be toxic at very low concentrations compared to typical background levels of commonly-used compounds (flame retardants, pesticides) that are chemically similar, spectroscopic measurements have the potential to reduce false alarms by distinguishing between dangerous and benign compounds. Unfortunately, most true spectroscopic instruments (infrared spectrometers, mass spectrometers, and gas chromatograph-mass spectrometers) are bench-top instruments. Surface-acoustic wave (SAW) sensors are commercially available in hand-held form, but rely on a handful of functionalized surfaces to achieve specificity. Here, we consider the potential for a hand-held device based on surface enhanced Raman scattering (SERS) using templated nanowires as enhancing substrates. We examine the magnitude of enhancement generated by the nanowires and the specificity achieved in measurements of a range of CWA simulants. We predict the ultimate sensitivity of a device based on a nanowire-based SERS core to be 1-2 orders of magnitude greater than a comparable SAW system, with a detection limit of approximately 0.01 mg m-3.

8373-77, Session 16

Nanomaterials and future aerospace technologies: challenges and opportunities

R. Vaia, Air Force Research Lab. (United States)

Two decades of extensive investment in nanomaterials, nanofabrication and nanometrology has provided the global engineering community a vast array of new technologies. These technologies not only promise radical change to traditional industries, such as transportation, information and aerospace, but may create whole new industries, such as personalized medicine and personalized energy harvesting and storage. The challenge for today is determining how to accelerate the conversion of these opportunities into concrete potential and quantifiable impact, as well as identifying the most important outstanding scientific questions that are limiting even greater utilization. Considering aerospace as an example, this talk will highlight opportunities that nanomaterials afford for some of the hardest technical challenges, including engineered resilient systems, autonomy and human systems. For example, nanomaterial fabrication delivers substantial tailorablity beyond a static material data sheet. How then can we integrate this tailorability into agile manufacturing and design methods to further optimize the performance, cost and durability of future resilient aerospace systems? Also, the intersection of nano-based metamaterials, smart surfaces and nanostructured devices with biology and biotechnology epitomizes the technological promise of autonomous systems that can achieve complex tasks in complex environments, and enhanced human-machine interfaces that ensure increased effectiveness and productivity of our human resources. What then are the key challenges that are limiting current lab-scale innovation from being integrated into functioning systems? These opportunities and associated challenges point toward future successes being based on highly effective, mutual communication and partnership between scientific innovation, manufacturing, and design.

8373-78, Session 16

Infrared imaging system using nanocarbon materials

N. Xi, Michigan State Univ. (United States)

Infrared (IR) detectors are enormously important for various civilian and military applications including medical diagnosis, IR imaging, night vision and surveillance etc. The efficiency and performance of traditional IR detectors are greatly confined by sensing materials. Besides, the current bottleneck of high-sensitive IR detectors is the requirement of cryogenic cooling to reduce the influence from other radiations. Novel nano carbon material, such as carbon nanotube and grapheme, are considered to be the most promising candidates for IR detectors . Nano carbon material based detectors exhibit extremely low dark current, low noise equivalent temperature difference (NETD), high response time, and high dynamic range. Most importantly, it can detect multiple spectrum infrared at room temperature. This unique feature can significantly reduce the size and weight of an IR imaging system by eliminating a cryogenic cooling system. However, there are two major difficulties that impede the application of nano carbon material based IR detectors for imaging systems. First, the small dimension of the nano carbon material based detector results in low fill factor. Secondly, it is difficult to fabricate large scale of the detector array for high resolution focal plane due to the limitations on the efficiency and cost of the manufacturing. In this paper, new nano carbon based IR imaging system is presented. Integrating the nano carbon material based detectors with photonic crystal wave guide, the fill factor of the detector can be significantly improved. Furthermore, using the compressive sensing technology, a high resolution imaging can be achieved. The experimental testing results show that the new imaging system can achieve the superb performance, and, at same time, overcame its difficulties to achieve high resolution and efficient imaging.

8373-79, Session 16

Identification of nanoscale films for THz sensing

G. Karunasiri, F. Alves, D. Grbovic, B. Kearney, Naval Postgraduate School (United States)

There is a continued interest in the terahertz (THz) spectral range due to potential applications in spectroscopy and imaging. Real-time imaging in this spectral range has been demonstrated using microbolometer technology with external illumination provided by quantum cascade laser based THz sources. To achieve high sensitivity, it is necessary to develop microbolometer pixels using enhanced THz absorbing materials. Metal films with thicknesses less than the skin depth for THz frequencies can efficiently absorb THz radiation. However, both theoretical analysis and numerical simulation show that the maximum THz absorption of the metal films is limited to 50%. Recent experiments carried out using a series of Cr and Ni films with different thicknesses showed that absorption up to the maximum value of 50% can be obtained in a broad range of THz frequencies. A further increase in absorption requires the use of resonant structures. These metamaterial structures consist of an Al ground plane, a SiO_2 dielectric layer, and a patterned Al layer. Nearly 100% absorption at a specific THz frequency is observed, which strongly depends on the structural parameters. In this presentation, the progress in the use of thin metal films and metamaterial structures as THz absorbers will be described.

8373-80, Session 16

InP- and graphene-based grating-gated transistors for tunable THz and mm-wave detection

R. E. Peale, N. Nader Esfahani, C. J. Fredricksen, G. Medhi, Univ. of Central Florida (United States); J. W. Cleary, Air Force Research Lab. (United States); W. R. Buchwald, Solid State Scientific Corp. (United States); J. Hendrickson, Air Force Research Lab. (United States); M. Ishigami, M. S. Lodge, B. D. Dawson, Univ. of Central Florida (United States)

Terahertz plasmons may be resonantly excited in the two dimensional electron gas (2DEG) of high electron mobility transistors (HEMTs) by coupling to incident THz radiation with a suitable grating structure for the gate. By changing the sheet charge density in the 2DEG, a bias applied to the gate can tune the plasmon resonance frequency. If there exists a coupling between the absorption by plasmons and the HEMT channel conductance, the device may be used as a voltage-tunable narrow band detector. We present here an investigation of the tunable Plasmon resonances in both InP and graphene-based HEMTs. The device transmittance spectrum is calculated as a function of gate bias, temperature, and layer and gate geometries. The device transmittance is measured using a Fourier spectrometer. Results suggest that the graphene-based device will operate to higher THz frequencies (up to 7 THz) and to higher temperature (room temperature) than the InP-based device. The latter has the advantage being fabricated from commercial HEMT wafers requiring only suitable metallization to form the HEMT. We seek the corresponding resonance change in channel conductance using a stable backward-wave-oscillator with frequency modulation and synchronous lock-in detection. The device has potential as a chip-scale spectral sensor for THz imaging and space-situational awareness.

8373-81, Session 16

Population inversion and terahertz lasing in graphene

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The interband population inversion can be realized in graphene layers (GLs) and non-Bernal stacked multiple-graphene layers (MGLs). The gapless energy spectrum in GLs and MGLs leads to the opportunity of creation of terahertz (THz) lasers with optical and electrical (injection) pumping. We review the current achievements in the area of THz sources and focus on our results on optically pumped GLs and MGLs, which account for the photogeneration of electrons and holes, their energy relaxation and recombination due to interaction with optical phonons.

The results of calculations of the dynamic THz conductivity associated with interband and intraband transitions as a function of the frequency, quasi-Fermi energies of electrons and holes, and the temperature are discussed. We review the conditions of realization of population inversion and negative dynamic conductivity in optically pumped GLs and MGLs in the THz range of frequencies, under which the THz lasing in GL and MGL structures under optical excitation can be achieved, particularly, at room temperature.

It is shown that the interplay between the optical phonon scattering and carrier-carrier interaction plays an important role in accomplishment of population inversion and negative dynamic conductivity. In particular, the latter can lead to both heating of the electron-hole system (complicating the realization of sufficient population inversion) and its cooling (which promotes a strong population inversion). Several designs of prospective THz lasers based on optically pumped GLs and MGLs (with Fabri-Perot resonator, slot-line wave-guide, dielectric wave-guide, as well as using the surface plasma waves along GLs or MGLs) are discussed.

8373-82, Session 17

Phenomenology and system engineering of micro- and nano-antenna FPA sensors for detection of concealed weapons and improvised explosive devices

R. Appleby, Queen’s Univ. Belfast (United Kingdom)

The ability of millimetre wave and terahertz systems to penetrate clothing is well known. The fact that the transmission of clothing and the reflectivity of the body vary as a function of frequency is less so. Several instruments have been developed to exploit this capability. The choice of operating frequency, however, has often been associated with the maturity and cost of the enabling technology rather than a sound systems engineering approach. Top level user and systems requirements have been derived for stand-off detection and against these, different architectures have been developed. Active and passive scanned and staring array systems operating at different frequencies have been considered along with emerging micro and nanotechnology concepts. These architectures are compared and contrasted and the strengths and weaknesses reported.

8373-83, Session 17

Introducing sub-wavelength pixel THz camera for the understanding of close pixel-to-wavelength imaging challenges

A. Bergeron, L. Marchese, D. G. Dufour, M. Bolduc, M. Terroux, É. Savard, B. Tremblay, E. Oulachgar, M. Doucet, L. Le Noc, C. Alain, H. Jerominek, INO (Canada)

The emergence of micro- and nano- structures and material in various technology areas is bringing new challenges to the understanding of the related physical phenomena. Prediction of properties and performances typically use models at the macroscopic level. While the physics behind the understanding of the phenomena itself remains unchanged, the use of standard models is facing challenges for close pixel-to-wavelength imaging conditions since the hypothesis used to generate them are no longer fully respected. An illustration of this is when the camera detector pixel size is comparable to the imaging wavelength. Though this is extremely rare in today’s imaging technology, terahertz (THz) is one emerging area where the pixel dimensions can be made smaller than the imaging wavelength. Terahertz radiation lies at an interesting point along the electromagnetic spectrum. Its frequencies of 0.3 THz to 10 THz (1 mm to 30 μm) place it at the intersection of two distinct regimes: classical electromagnetic (i.e. radio, microwave) and optical (i.e. visible, infrared). Research exploiting both the electromagnetic and optical properties of THz radiation continues for both generation and detection has shown great advancement. This paper discusses the modification by INO of its infrared MEMS microbolometer detector technology toward a THz imaging platform yielding a sub-wavelength pixel THz camera. The results obtained with this sub-wavelength pixel based camera in close pixel-to-wavelength imaging are reviewed in this paper. Parameters such as imaging resolution and sampling are addressed.

8373-84, Session 17

Optimal coherent control methods for explosives detection

D. S. Moore, S. D. McGrane, M. T. Greenfield, R. J. Scharff, Los Alamos National Lab. (United States)

The detection of explosives is a notoriously difficult problem, especially at stand-off distances, due to their (generally) low vapor pressure, environmental and matrix interferences, and packaging. We are exploring optimal dynamic detection of explosives (ODD-Ex) to exploit the best

capabilities of recent advances in laser technology and recent discoveries in optimal shaping of laser pulses for control of molecular processes to significantly enhance the standoff detection of explosives. The core of the ODD-Ex technique is the introduction of optimally shaped laser pulses to simultaneously enhance sensitivity of explosives signatures while reducing the influence of noise and increasing specificity over background and interfering materials in the field. Recent results for ODD optimized coherent anti-Stokes Raman spectroscopy demonstrate the capability of the method for trace explosives both on a variety of surfaces and in obscuring solutions.

8373-85, Session 17

Photodetection with active optical antennas

N. J. Halas, Rice Univ. (United States)

We report an active optical antenna device that utilizes the hot electron-hole pairs resulting from plasmon decay to directly generate a photocurrent, resulting in the detection of light. This is accomplished by a nanoantenna fabricated on a semiconductor surface where a metal-semiconductor, or Schottky barrier, is formed at the antenna-semiconductor interface. When this type of antenna is photoexcited it generates electron-hole pairs, with hot electrons that are injected into the semiconductor over the Schottky barrier, contributing to a detectable photocurrent. In this configuration, photocurrent generation is no longer limited to photon energies above the bandgap of the semiconductor, but rather to photon energies above the Schottky barrier height. Therefore this device is capable of detecting light well below the bandgap of the semiconductor, with a cutoff wavelength determined by the barrier inherent to the antenna-semiconductor interface. Light detection with this device occurs at room temperature and without a bias voltage. The photocurrent obtained from these devices is determined directly by the antenna properties. Photocurrent curves show a strong wavelength dependence resulting from the antenna geometry, with maximum currents increasing in wavelength with increasing antenna length. The spectral response directly follows the longitudinal dipole resonance of the plasmon mode excited on the structure. The photocurrent also follows that of the nanoantennas with a highly polarization dependent response. Incident power variation at a single wavelength results in a linear response of the photocurrent, corresponding to the conversion of single photons to single hot electrons.

8373-86, Session 17

Canadian approaches for chemical, biological and explosive standoff detection

S. Désilets, J. Thériault, J. Simard, Defence Research and Development Canada, Valcartier (Canada)

Chemical agents, biological species and explosive residues are threatening materials of different natures that may be found under various trace levels. While chemicals are usually spread in vapour or liquid phases, biological agents are mostly dispersed in aerosol forms that will ultimately produce very low concentration of surface contaminations. By comparison, explosives are mostly found in trace amounts on surfaces. This presentation will illustrate different approaches that have been taken for the standoff detection of chemical, biological and explosives based on the electro-optical sensing of material properties. A particular emphasis will be put on the quantity and the nature of the material to detect.

8373-87, Session 18

QCL as a game changer in mid-IR standoff military applications

C. K. N. Patel, Pranalytica, Inc. (United States)

QCLs represent an important advance in MWIR and LWIR laser technology. With the demonstration of CW/RT QCLs, large number applications for QCLs have opened up, some of which represent replacement of currently used laser sources such as OPOs and OPSELs, and others being new uses which were not possible using earlier MWIR/LWIR laser sources, namely OPOs, OPSELs and CO2 lasers.

Pranalytica has made significant advances in CW/RT power and WPE of QCLs and through its invention of a new QCL structure design, the non-resonant extraction , has demonstrated single emitter power of >4.7 W and WPE of >17% in the 4.4μm-5.0μm region. Pranalytica has also been commercially supplying the highest power MWIR QCLs with high WPEs. The NRE design concept now has been extended to the shorter wavelengths (3.8μm-4.2μm) with multiwatt power outputs and to longer wavelengths (7μm-10μm) with >1 W output powers. The high WPE of the QCLs permits RT operation of QCLs without using TECs in quasi-CW mode where multiwatt average powers are obtained even in ambient T>70°C. The QCW uncooled operation is particularly attractive for handheld, battery-operated applications where electrical power is limited.

I will elaborate on the advances in QCL technology and describe applications of the high power MWIR and LWIR QCLs for defense applications, including protection of aircraft from MANPADS, standoff detection of IEDs, in-situ detection of CWAs and explosives, infrared IFF beacons and target designators. We see that the SWaP advantages of QCLs are rule changers.

8373-88, Session 18

Standoff detection of explosive residues on unknown surfaces

C. W. Van Neste, X. Liu, L. L. Norman, M. Gupta, S. Kim, Y. Y. Tsui, T. G. Thundat, Univ. of Alberta (Canada)

Standoff identification of explosive residues may offer early warnings to many hazards plaguing present and future military operations. The greatest challenge is posed by the need for molecular recognition of trace explosive compounds on real-world surfaces. Most techniques offering long-range, eye safe techniques fail when there exists no prior knowledge of the surface being interrogated. Surface inhomogeneity and optical absorption from background molecules can introduce significant reproducibility issues for these systems when residue concentrations are below tens of micrograms per square centimeter. Here we present a coupled standoff technique that allows identification of explosive residues in the sub microgram per square centimeter concentration on real-world surfaces. Our technique is a variation of standoff photoacoustic spectroscopy merged with ultraviolet chemical photodecomposition for selective identification of explosives. We demonstrate the detection of standard military grade explosives including RDX, PETN, and TNT along with a few common compounds such as diesel, sugar, and potassium chloride (a fertilizer molecule). We obtain identification of these residues at several hundred nanograms per square centimeter from a distance of ten meters.

8373-89, Session 18

Broadband tunable external cavity quantum cascade lasers for standoff detection of explosives

S. Hugger, F. Fuchs, M. Kinzer, Q. Yang, W. Bronner, R. Aidam, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); K. Degreif, Fraunhofer-Institut für Physikalische Messtechnik (Germany); F. Schnürer, Fraunhofer-Institut für Chemische Technologie (Germany)

Today's detection methods for explosives that allow sampling have reached very high sensitivity. In contrast, reliable stand-off detection of trace explosives, although highly desirable, is still a formidable challenge. Optical techniques based on laser spectroscopy represent a natural approach for contactless investigations from save distances. Organic chemical compounds typically exhibit strong characteristic absorbance patterns in the mid-infrared (MIR) within the range of the third atmospheric transmission window (8 µm - 14 µm). Quantum cascade lasers are compact, robust and wavelength-versatile MIR-semiconductor lasers and provide ideal illumination sources for this purpose.

We developed a mobile system for the detection of solid traces of explosives on surfaces using hyperspectral image analysis. The system relies on active laser illumination, synchronized with the collection of the backscattered radiation by an infrared camera. The key component is an external cavity quantum cascade laser with a tuning range of 300 cm-1 that enables us to scan the illumination wavelength over several of the characteristic absorption features of a large number of different explosives using a single source.

We investigated traces of various explosives including e.g. PETN, TNT and RDX on different substrate-materials. For medium distances (< 3 m), concentrations down to some 10 µg/cm2 can be detected. For higher material concentrations, we demonstrate detection distances up to 28 m. The large tuning range of the laser proved to be crucial both for the ability to identify most of the relevant explosives as well as for reliable suppression of cross-sensitivity to other substances.

8373-90, Session 18

Infrared photothermal imaging for standoff detection applications

C. A. Kendziora, R. Furstenberg, M. R. Papantonakis, V. Q. Nguyen, R. A. McGill, U.S. Naval Research Lab. (United States)

We are developing a technique for the stand-off detection of trace analytes (explosives, chemicals, drugs, etc.) using infrared (IR) photo-thermal imaging. This approach leverages recent developments in critical enabling micro and nano-technology components. The first component, a compact IR quantum cascade laser, is tuned to strong absorption bands in the trace analytes and directed to illuminate a surface of interest. The second component, an IR focal plane array (FPA), is used to image the surface and detect any small increase in the thermal emission upon laser illumination. We demonstrate the technique at several meters of stand-off distance indoors and in field tests, while operating the lasers below the eye-safe intensity limit (100 mW/cm2). Sensitivity to explosive traces as small as a single grain (~1 ng) has been demonstrated. Using a sequence of lasers at different wavelengths, we increase both sensitivity and selectivity while reducing the false alarm rate. We compare results with cooled and uncooled FPAs and examine the advantages of filtering the collected light signal. This talk will include an overview of the approach and recent experimental results.

References: R. Furstenberg et al. Applied Physics Letters 93, 224103 (2008), C. A. Kendziora et al.; Proc. of SPIE Vol. 7664 76641J-1 (2010). R. Furstenberg et al.; Proc. of SPIE Vol. 8013, 801318 (2011).

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8373-91, Session 18

High-power, military ruggedized QCL-based laser systems

E. B. Takeuchi, W. B. Chapman, T. Day, D. B. Arnone, M. Pushkarsky, D. B. Caffey, M. B. Young, Daylight Solutions Inc. (United States)

Daylight Solutions has pioneered the development and commercialization of quantum cascade laser (QCL) technology for commercial and military markets. Multi-Watt, multi-wavelength QCL-based systems have been manufactured and tested against harsh military environmental requirements for military applications. These self-contained, turn-key systems have been designed to comply with modular open system architecture (MOSA) principles, and have been proven in several different system geometries. Daylight will provide a review of the background QCL technology, and current state-of-the-art performance of commercially available devices. Daylight will review the advantages that can be derived from QCL technology as they relate to military applications and their impact on system level performance.

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8374-01, Session 1

Progress in fieldable LIBS

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The Laser Induced Breakdown Spectroscopy (LIBS) technology field has been recognized for some time as an emerging new tool for protection and security applications based on an exponential growth in published works that show great potential for the analysis of all 5 out of 5 major threat areas- CBRNE. These successes using benchtop systems are now evolving into a new generation of fieldable LIBS devices so that the potential can now be realized in real-world applications. The ability of LIBS to provide useful data and performance in the field is already well-established with a large number of LIBS devices being used in industry for applications such as geology, mining, glass manufacture, smelting operation, as well as recycling materials identification, amongst others. In fact, there is a LIBS sensor that is part of the Chemcam system that is scheduled to fly to Mars in the next mission in late 2011. However, the transition of LIBS devices for complex field analyses of threats, especially when these are in the form of trace materials on a wide variety of real-world substrates, is indeed a difficult challenge not only for LIBS, but for any sensing technology. There are now fieldable commercial LIBS devices which include a close-contact, as well as a swab analyzer which operate on battery power. There are also systems for standoff threat analysis up to 100 meters standoff range, as well as systems that analyze submerged materials. These will be discussed at the presentation.

8374-02, Session 1

Field-portable, time-resolved SORS sensor for the identification of concealed hazards

B. Cletus, Queensland Univ. of Technology (Australia)

Raman spectroscopy, when used in spatially offset mode, has become a potential tool for the identification of explosives and other hazardous substances concealed in opaque containers. The molecular fingerprinting capability of Raman spectroscopy, together with its relatively small size and portability, makes it an attractive tool for the unambiguous identification of hazardous substances in the field. Additionally, minimal sample preparation is required compared with other techniques.

We report a field portable timeresolved Raman sensor for the detection of concealed chemical hazards in opaque containers. The new sensor uses a pulsed nanosecond laser source in conjunction with an image intensified CCD detector. The new sensor employs a combination of time and space resolved Raman spectroscopy to enhance the detection capability. The new sensor also makes the data handling easy for the identification of concealed hazards.

8374-03, Session 1

Miniature near-infrared (NIR) spectrometer engine for handheld applications

N. A. O'Brien, D. Friedrich, C. A. Hulse, F. Van Milligen, M. Von Gunten, JDSU (United States)

In this paper, we report on the first ever near-infrared (NIR) miniature spectral engine built with a linear variable filter (LVF) as the dispersing element covering the wavelength range of 900 nm-1700 nm or 1150 nm-2100 nm. LVF is a thin-film Fabry Perot bandpass filter whose thickness is intentionally wedged in one dimension such that the center wavelength of the bandpass is continuously varying across the length of the filter. When the LVF component is attached to a one dimensional linear detector array, a miniature spectrometer is realized enabling handheld, portable, or on-line sensor applications.

The NIR spectral engine is built with an integrated tungsten light source, a multi-pixel element indium gallium arsenide (InGaAs) detector array, custom collimating optics, and electronics, resulting in an engine that weighs less than 50 grams and measures less than 40mm3 in size. The LVF is brought in close proximity to the detector array and replaces the detector window. We have built the engine with an uncooled InGaAs detector to keep the cost, weight, and size as low as possible for field-use applications. The engine can be used in transmission or diffuse reflectance for the measurements of liquid or solid compounds respectively. The LVF thin-film design has been optimized to enable resolution of FWHM that is less than 1.5% of center wavelength, with reduced stray light. We demonstrate the spectral performance in a number of applications. Other performance attributes such environmental performance, repeatability, signal to noise, and acquisition time will be shared and discussed.

8374-04, Session 1

Recent developments toward low-cost, miniaturized spectrometers for field applications

D. K. Silva, J. Antoszewski, T. Nguyen, J. M. Dell, L. Faraone, The Univ. of Western Australia (Australia)

Infrared (IR) spectroscopy is finding increasing application in numerous industries including, pharmaceuticals, agriculture, viticulture, remote sensing, and defense. However, the cost, weight, and fragility of traditional bench-top spectrometers remain a key stumbling point for the widespread application of IR spectroscopy in many of these industries. Particularly for application in Agriculture, the need for low cost, small and rugged spectroscopy instruments is immense. Much progress has been made in the development of miniaturized spectrometers, by a number of groups.

Miniature spectrometers have been demonstrated of various designs including grating-based, Fourier Transform, and Fabry Perot. Varying degrees of miniaturization are evident in these designs. Whilst some operate simply with smaller versions of the original components, others take miniaturization to the point of implementation in microelectromechanical systems (MEMS). Furthermore, while some of these technologies are specifically suited to single-point detection of samples, others are potentially extensible to multispectral and hyperspectral imaging applications.

Miniature spectrometers commonly exhibit limitations in spectral scan-range and resolution. Although these limitations restrict the application of the systems, their utility within the restricted scope is significant. This paper reviews the work of key players, including the authors' own research group, towards realization of miniaturized spectrometers. The strengths and limitations of each technology are identified and compared in terms of spectral range and resolution, estimated or actual cost, potential for imaging applications, and robustness and suitability for fields use. Based on these strengths and limitations, possible industries of use are identified for each technology.

8374-05, Session 1

Advances in handheld FT-IR instrumentation

J. Arnó, L. Cardillo, M. Frayer, M. Frunzi, P. Hetherington, D. Levy, K. Oberndorfer, W. Perec, T. Sauer, J. T. Stein, E. Zuidema, Smiths Detection (United States)

FT-IR spectroscopy is the technology of choice to identify solid and liquid phase unknown samples. The challenging ConOps in emergency

response and military field applications require a significant redesign of the stationary FT-IR bench-top instruments typically used in laboratories. Specifically, field portable units require high levels of resistance against mechanical shock and chemical attack, easy of use in restrictive gear, quick and easy interpretation of results, and reduced size. In the last 20 years, FT-IR instruments have been re-engineered to fit in small suitcases for field portable use and recently further miniaturized for handheld operation. This article introduces a new FT-IR instrument designed to balance the portability advantages of a handheld device with the performance challenges associated with miniaturization. The instrument features a permanently aligned cube corner interferometer for improved robustness and large optics (0.5" diameter) to maximize optical throughput and signal-to-noise ratios. Sample analysis can be achieved using the primary ATR press or via direct contact using the touch-to-sample option. User interface was carefully created for military and emergency response applications to provide actionable information in a visual and intuitive format. Similar to the HazMat family of products, state-of-the-art algorithms are used to quickly identify the chemical composition of complex samples based on the spectral information. This article includes an overview of the instrument's features and capabilities for the broad identification of chemicals for defense, emergency response, and security applications. Tests results and performance validation of the mechanical ruggedness, spectral performance, and unknown identification will be emphasized.

8374-06, Session 2

Investigation of optically injected charge carrier dynamics with THz spectroscopy

T. Arnold, M. DeBiasio, R. Leitner, Carinthian Tech Research AG (Austria)

Terahertz time-domain spectroscopy can be used to characterize silicon solar cell properties such as: conductivity, charge carrier mobility and density. Moreover, THz spectroscopy and imaging can be used for defect analysis in semiconductor and photovoltaic materials. This paper describes the investigation of optically injected charge carrier dynamics by the use of THz spectroscopy. THz-pump/THz-probe measurements were carried out at different measurement positions on silicon wafers which were illuminated by a halogen light source. Initial results indicate that THz time-domain spectroscopy is promising technique for the contactless characterization of silicon wafers for photovoltaic industry. A great benefit of the THz measurements is that the presence of electric contacts for the characterization of the silicon wafers is not necessary and can thus be done at the beginning of the production process of a photovoltaic cell. Well established techniques for the characterization of photovoltaic cells like electro luminescence, photo luminescence, thermography or voltage and current measurements require a contacted photovoltaic cell and can thus only be carried out at the end of the production process.

8374-07, Session 2

Single-component versatile spectrometer chip for sensing applications

S. J. Sweeney, Y. Zhang, I. D. Goodyer, ZiNIR Ltd. (United Kingdom)

An entirely new type of monolithic, chip-based spectrometer based on resonant coupling within a III-V compound semiconductor platform is presented for applications in defence and security. A series of semiconductor resonators have been designed to both select and detect wavelengths forming a highly integrated and truly single-component spectrometer. The concept utilises resonant detection via optically active semiconductor disk micro-resonators which provide high wavelength selectivity and tunability together with photo-detection. As well as being solid-state and having no moving parts, the co-location of wavelength dispersion and detection has the potential for excellent spectral responsivity. By varying the dimensions and composition of the resonator design, this generic approach may be used to develop spectrometers that operate in the UV, visible and infrared ranges.

In this paper we describe a spectrometer chip targeting a specific region of the near-infrared (NIR) region for application in stand-off detection. The requirements for the size and composition of the resonators and ridge waveguide for optimisation of the measured spectral signal will be discussed. A prototype spectrometer chip, based on InP, targeting a 10nm NIR region has been realised. Initial results on the prototype spectrometer chip will be presented highlighting the spectral and electrical performance.

This novel design provides a spectrometer chip that has a number of advantages over other technologies. It can withstand extreme temperatures, water and dust and is maintenance free. This is a spectrometer chip to take into harsh and difficult to access environments, or to embed into clothing, vehicles or electronic equipment.

8374-08, Session 2

Time-resolved absolute spectral analysis of IR countermeasure flares and its experimental validation by using an optical emission spectrometer with PbSe array detector

H. Lee, C. Oh, J. W. Hahn, Yonsei Univ. (Korea, Republic of)

Modern warfare has classified the stealth technology or so called low observability as important features. Much development in IR countermeasures field has formed a part of the program and as a result, decoy flare technology was widely accepted as an attractive methods. Although flare technology researches have been studied for infrared signatures, limited details can be found in the open academic literature and experimental validation is also needed for developing IR signature prediction models.

We, in that context, developed a miniaturized optical emission spectrometer (OES) for experimental validation including measurement of the absolute spectral radiant exitance of IR signatures. Using a high-temperature blackbody operated at a temperature of 2000 K, the spectral response of the OES in the mid-IR (MWIR) spectral range was calibrated. The uncertainty of the absolute measurement of the IR signature was analyzed by considering various uncertainty budgets, and the total uncertainty was found to be 1.57%. To evaluate the usefulness of the IR-OES, the time-resolved emission spectra of various IR signatures from both countermeasure flares and propellants were measured and total amount of their emission was calculated. Emission spectrums within the spectral range of 2 to 5 μm were recorded by means of the miniaturized MWIR spectrometer and the optically designed measurement module, and it was experimentally confirmed that water vapour emission was stronger near 2.8 μm, while carbon dioxide emission at 4.5 μm. Our suggested tools and methods are of extreme importance to the field of advanced countermeasures including IR countermeasure flares.

8374-09, Session 3

Multi- and hyperspectral UAV imaging system for forest and agriculture applications

J. H. Mäkynen, H. Saari, C. Holmlund, K. Ojala, T. Antila, VTT Technical Research Ctr. of Finland (Finland)

VTT Technical Research Centre of Finland has developed a Fabry-Perot Interferometer (FPI) based hyperspectral imager compatible with the light weight UAV platforms (SPIE Proc. 7474, 8186B). The FPI based hyperspectral imager was used in the UAV imaging campaigns for forest and agriculture test areas during summer 2011 (SPIE Proc. 8174). During summer 2011 the high spatial resolution Color-Infrared (CIR) camera images and hyperspectral images were recorded on separate flights. The system which includes both the high spatial resolution Color-Infrared (CIR) camera and light weight hyperspectral imager can

provide all necessary data with just one UAV flight over the target area. The new UAV imaging system contains a 5 Mpixel CIR camera which is used for the generation of the digital surface models and CIR mosaics. The hyperspectral data can be recorded in the wavelength range 500 - 900 nm at a resolution of 10 - 30 nm at FWHM. The resolution can be selected from approximate values of 10, 15, 20 or 30 nm at FWHM. The design and calibration of the system will be presented.

8374-10, Session 3

Simple XRD algorithm for direct determination of cotton cellulose crystallinity

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Traditionally, X-ray diffraction (XRD) had been used to study the crystalline structure of cotton celluloses. Despite considerable efforts in developing the curve-fitting protocol to evaluate the crystallinity index (CI), in its present state, XRD measurement can only provide a qualitative or semi-quantitative assessment of the amounts of crystalline and amorphous cellulosic components in a sample. The greatest barrier to establish quantitative XRD is the lack of appropriate cellulose standards needed to calibrate the measurements. In practical, samples with known CIs are very difficult to be prepared or determined. As an approach, we might assign the samples with reported CIs from FT-IR procedure, in which the three-band ratios were first calculated and then were converted into CIs within a large and diversified pool of cotton fibers. This study reports the development of simple XRD algorithm, over time-consuming and subjective curve-fitting process, for direct determination of cotton cellulose CI by correlating XRD with the FT-IR CI references.

8374-11, Session 3

A small, low-cost, hyperspectral imaging FTIR sensor design for standoff detection applications

T. C. Gruber, Jr., B. Moore, B. Tercha, R. Bowe, MESH, Inc. (United States)

Hyperspectral sensors allow standoff visualization and identification of chemical vapor plumes; however, currently available COTS sensors, which produce very high quality data, are expensive (>$750k), large (>100 L), and massive (>30 kg). Man-portable and UAV based hyperspectral sensor applications require smaller and lighter weight designs. A new approach using new technologies, including a microbolometer IR camera, a piezo-electric linear actuator, a FPGA/LAN board, and an embedded multi-core CPU, is presented that seeks to produce similar quality hyperspectral data at a 10x cost reduction, 3x size reduction (<30 L), and a 3x mass reduction (<10 kg for optics and electronics). The design challenges, system overview, signal model, and initial performance data measurements from the new spectrometer design are presented along with examples of a man-portable sensor design version and a UAV/gimbal integrated sensor design version. An overview of the signal processing, including spatial co-adding, re-sampling to a uniform interferogram data point spacing, phase correction, and detection algorithms, is presented. Calibration methods and a comparison of the new spectrometer design to a standard MCT detector FTIR are also discussed.

8374-12, Session 3

Video-rate chemical identification and visualization with snapshot hyperspectral imaging

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Hyperspectral imaging has important benefits in remote sensing and target discrimination applications. This paper describes a class of snapshot-mode hyperspectral imaging systems which utilize a unique optical processor that provides video-rate hyperspectral datacubes. This system consists of numerous parallel optical paths which collect the full three-dimensional (two spatial, one spectral) hyperspectral datacube with each video frame and are ideal for recording data from transient events, or on unstable platforms.

We will present the results of laboratory and field-tests for several of these imagers operating at visible, near-infrared, MWIR and LWIR wavelengths. Measurement results for nitrate detection and identification as well as additional chemical identification and analysis will be presented.

8374-13, Session 3

X-ray diffraction imaging and tomographic reconstruction

K. Chen, D. Castanon, Boston Univ. (United States)

Material discrimination based on conventional or dual energy X-ray computed tomography (CT) imaging can be ambiguous. X-ray diffraction imaging (XDI) can be used to construct diffraction profiles of objects, providing new molecular signature information that can be used to characterize the presence of specific materials. Combining X-ray CT and diffraction imaging can lead to enhanced detection and identification of explosives in luggage screening. Current XDI scanners are based on direct imaging rather than tomographic imaging, which require the use of line collimators to localize scattering location and thus result in slow scan performance. In an effort to gain faster scan time and better signal-to-noise ratio, in this work we are investigating tomographic inversion techniques for joint reconstruction of CT absorption and X-ray diffraction profile images of object. We present a fast iterative reconstruction algorithm with geometric feature preserving regularization (IREP) using form-factor wise based iterative coordinate descent (ICD). We validate the initial results via numerical simulation of X-ray absorption and coherent scattering in 2 dimensions, and compare the performance of the IREP algorithm with existing inversion techniques such as algebraic reconstruction (ART) and modified three-dimensional filtered back-projection (FBP) algorithm. The experimental results show that the proposed method offers improved image quality for enhanced material classification.

8374-14, Session 4

Thermal hyperspectral chemical imaging

H. Holma, T. Hyvärinen, A. Mattila, Specim Spectral Imaging Ltd. (Finland)

Several chemical compounds have their strongest spectral signatures in the thermal region. This paper presents three push-broom thermal hyperspectral imagers. The first operates in MWIR (2.8-5 um) with 35 nm spectral resolution. It consists of uncooled imaging spectrograph and cryogenically cooled InSb camera, with spatial resolution of 320/640 pixels and image rate to 400 Hz. The second imager covers LWIR in 7.6-

12 um with 32 spectral bands. It employs an uncooled microbolometer array and spectrograph. These imagers have been designed for chemical mapping in reflection mode in industry and laboratory. An efficient line-illumination source has been developed, and it makes possible thermal hyperspectral imaging in reflection with much higher signal and SNR than is obtained from room temperature emission. Application demonstrations including sorting of dark plastics and mineralogical mapping of drill cores are presented.

The third imager utilizes a cryo-cooled MCT array with precisely temperature stabilized optics. The optics is not cooled, but instrument radiation is suppressed by special filtering and corrected by BMC (Background-Monitoring-on-Chip) method. The approach provides excellent sensitivity in an instrument which is portable and compact enough for installation in UAVs. The imager has been verified in 7.6 to 12.3 μm to provide NESR of 18 mW/(m2 sr um) at 10 um for 300 K target with 100 spectral bands and 384 spatial samples. It results in SNR of higher than 500. The performance makes possible various applications from gas detection to mineral exploration and vegetation surveys. Results from outdoor and airborne experiments are shown.

8374-15, Session 4

Spectral imaging device based on a tuneable MEMS Fabry-Perot interferometer

J. E. Antila, VTT Technical Research Ctr. of Finland (Finland); U. Kantojärvi, VTT Information Technology (Finland); R. Mannila, A. Rissanen, VTT Technical Research Ctr. of Finland (Finland)

The trend in the development of single-point spectrometric sensors is miniaturization, cost reduction and increase of functionality and versatility. MEMS Fabry-Perot interferometers (FPI) have been proven to give answers to many of these questions in the form of miniaturised spectrometer modules and tuneable light sources. VTT's recent development of MEMS FPI devices based on ALD thin film structures potentially addresses all of these main trends. In this paper we present a device and first measurement results of a small imaging spectrometer utilizing a 2-mm tuneable MEMS FPI filter working in the visible range of 430-580 nm. The construction and properties of the filter are explained especially from imaging requirements point of view.

8374-16, Session 4

High-resolution SWIR hyperspectral imaging: a new approach based on volume Bragg grating

S. Blais-Ouellette, M. Verhaegen, S. Lessard, Photon etc. Inc. (Canada)

Volume Bragg grating technology has enabled the development of a new type of staring hyperspectral camera. Based on Bragg Tunable filters, these hyperspectral cameras have both high spectral and spatial resolution, and significantly higher sensitivity than competing technologies like liquid crystal tunable filters and acousto-optic tunable filters. They are minimally sensitive to polarization and their spectral out-of-band rejection can reach 106 . Here we thus present an innovative tool to collect SWIR hyperspectral data with high spectral and spatial resolution. This new instrument is based on a 3nm bandwidth Bragg Tunable Filter, continuously tunable in wavelength from 1.0um and 2.5um. Because high spectral resolution also means less light per channel, a low noise custom HgCdTe (MCT) camera was also developed to meet the requirement of the filter. The high speed capability of more than 200 fps and the low operating temperature of 200K (deep cooled option to 77K) allow full frame 500 spectral channel datacube acquisitions in minimal time. Basic principle of this imaging filter will be reviewed as well as the custom MCT camera performances. High resolution hyperspectral measurements will be demonstrated between 1.0um and 2.5um on different objects of interest.

8374-17, Session 5

Mid-IR interband cascade lasers operating with < 30 mW of input power

J. R. Meyer, W. W. Bewley, C. D. Merritt, C. S. Kim, C. Canedy, I. Vurgaftman, J. Abell, M. Kim, U.S. Naval Research Lab. (United States)

A recent design innovation for the type-II antimonide interband cascade laser (ICL) has improved the performance to a level far beyond any reported previously. Broad-area devices emitting at wavelengths of 3.0-4.1 microns display pulsed threshold current densities of 170-260 A/cm2 at T = 27 ºC. An epitaxial-side-up ridge with gold electro-plating operated in cw mode to 109 ºC. At 25 ºC, another ridge emitted up to 159 mW of cw power with 10% wallplug efficiency. The wallplug efficiency for a shorter cavity was as high as 13.5% at 25 ºC.

Two wafers were designed for emission at 4.6 microns and 5.5 microns. Although the threshold current densities were somewhat higher (650 A/cm2 for the longest wavelength) cw operation to temperatures well above ambient was nonetheless observed. One operated to 60 ºC at = 4.9 m, while the other operated to 50 ºC at 5.7 microns. Both generated 15 mW of cw output power at T = 25 ºC.

Probably the most significant observation of cw lasing at a remarkably low input power of 29 mW, which is more than 25 times lower than the best QCL value reported to date. This signifies a 1-2 orders of magnitude extension of the battery lifetime for fielded chemical sensing systems. Earlier-generation DFB ICLs displayed cw output powers up to 45 mw into a single spectral mode at a thermoelectric cooler temperature.

8374-18, Session 5

Monolithic, integrated-optic TDLAS sensors and networks

M. B. Frish, R. T. Wainner, Physical Sciences Inc. (United States)

For Chemical Weapon Agent (CWA) and Toxic Industrial Compound (TIC) detection, we are developing prototype chip-scale low-power integrated optic gas-phase chemical sensors based on infrared Tunable Diode Laser Absorption Spectroscopy (TDLAS). TDLAS is able to sense many TICs and CWAs with high sensitivity and selectivity, and low false alarm rate. Using semiconductor fabrication and assembly techniques, the low-cost integrated optic TDLAS technology will be an advance in laser-based chemical sensing, permitting mass production of sensors that have wide ranging industrial, medical, environmental, and consumer applications. Novel gas sensing elements using solid-state optical waveguides will permit monolithic integration of a laser source, sampling elements, and detector on a semiconductor materials system substrate. Many hundreds or thousands of such sensors can therefore be distributed cost-effectively over a wide area of interest and communicate among each other via a wireless network.

A key technical issue inhibiting cost-effective integration on a monolithic platform is minimizing the power consumed and discarded as waste heat to stabilize laser temperature with the precision needed for sensitive spectroscopic detection. Current laser packages utilize power-inefficient Peltier devices to provide the precise temperature control needed for sensitive gas detection. They are expensive, bulky, and power hungry. With both a near-IR InGaAs DFB laser and a mid-IR Quantum Cascade laser, we have demonstrated that the laser waste heat can be exploited to stabilize the laser at an operating temperature above ambient, thereby virtually eliminating the power drawn by the Peltier devices.

SPIE Defense, Security+Sensing

8374-19, Session 5

Recent advances in mid-IR external-cavity, quantum cascade laser performance

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The mid-IR portion of the spectrum is of great interest to a number of researchers and Quantum Cascade Lasers are proving to be an efficacious method to gain access to 3-12 μm light and beyond. Highly desirable properties including access to wavelengths of interest, high brightness, power, and coherence, and broad tunability continue to show markedly improved performance. Further, precise packaging provides for field-ready ruggedness, high efficiency, precision wavelength control, narrow linewidth, and phase continuous (mode hop-free) tuning.

Almost all molecules absorb selectively and strongly in the mid-IR. In addition to applications such as countermeasures and illumination, ECqcL (External Cavity Quantum Cascade Lasers) continue to serve the spectroscopist in ever-expanding capacity. Compact broad tuning lasers can combine high selectivity and sensitivity to serve as the engine for sensing target analytes in many environments, including in stand-off explosives detection and hospital environments. Coupled to microscopes, ECqcL can provide high-resolution, even sub-diffraction limited, images with chemical specificity. High resolution, mode hop-free tuning, a precision-built tuning mechanism, and expanded modulation functionality enable fundamental studies and selective detection of light, gas phase molecules with overlapping rotationally resolved spectra.

Advances in laser performance and design, including stability enhancements, newly available wavelengths, new cavity configurations and packaging, improved tunability, and redesigned modulation circuitry will be presented. Results from specific spectroscopic techniques will also be summarized.

8374-20, Session 5

Monolithic, widely tunable quantum cascade laser

K. M. Lascola, R. P. Leavitt, J. D. Bruno, J. L. Bradshaw, J. T. Pham, F. J. Towner, Maxion Technologies, Inc. (United States)

Maxion Technologies has designed a monolithic, widely tunable Quantum Cascade (QC) laser for use in chemical sensing applications. This multi-section QC laser is a monolithically tunable device, similar to those demonstrated in the near IR for telecommunications. Wideband tuning is achieved through grating assisted coupling of the optical mode between lateral waveguides, allowing ~10 times the tuning range normally achieved by distributed feedback lasers without incorporation of external optical elements. Compared to implementations in the near IR, the use of lateral waveguides (rather than vertically stacked waveguides) allows the optical mode to maintain the high overlap with the active region necessary for room temperature lasing the the mid-IR. Due to its monolithic configuration, this laser is expected to be rapidly tunable and usable in field environments due to its insensitivity to shock and vibration, while the wide tuning range of the device will allow for enhanced ability to discriminate against background chemicals. Detailed modeling results for the waveguide structures as well as preliminary device data demonstrating the tuning mechanism in a laser emitting at 7.7 um will be presented.

8374-21, Session 5

High-performance interband cascade lasers emitting between 3.3 and 3.5 microns

J. D. Bruno, J. L. Bradshaw, K. M. Lascola, R. P. Leavitt, J. T. Pham, F. J. Towner, R. A. Vohra, Maxion Technologies, Inc. (United States)

Semiconductor laser performance in the 3 to 4 micron wavelength region has lagged behind lasers at longer and shorter wavelengths. However, recent advances by the group at the Naval Research Laboratory (NRL) have markedly changed this situation, and in a recent collaboration with the NRL group, we demonstrated high performance interband cascade lasers at 3.8 microns. In this work, we present results extending the earlier work to shorter wavelengths. In particular, we designed four new interband cascade lasers at target wavelengths between 3.3 and 3.5 microns. Initial testing of broad area devices show threshold current densities of ~230 A/cm2 at 300K, almost a factor of two lower than the ~425 A/cm2 results obtained on the broad area devices at 3.8 microns. In this presentation, we will present performance data on these broad area lasers and also data on narrow ridge devices fabricated from the same material.

8374-22, Session 5

Detection and quantification of explosives and CWAs using a handheld, widely tunable quantum cascade laser

E. R. Deutsch, F. G. Haibach, A. Mazurenko, Block Engineering, LLC (United States)

The requirements for standoff detection of Explosives and CWA/TICs on surfaces in the battlefield are challenging because of the low detection limits. The variety of targets, backgrounds and interferences increase the challenges. Infrared absorption spectroscopy with traditional infrared detection technologies, incandescent sources that offer broad wavelength range but poor spectral intensity, are particularly challenged in standoff applications because most photons are lost to the target, background and the environment. Using a brighter source for active infrared detection e.g. a widely-tunable quantum cascade laser (QCL) source, provides sufficient spectral intensity to achieve the needed sensitivity and selectivity for explosives, CWAs, and TICs on surfaces. Specific detection of 1-10 μg/cm2 is achieved within seconds.

CWAs, and TICs in vapor and aerosol form present a different challenge. Vapors and aerosols are present at low concentrations, so long pathlengths are required to achieve the desired sensitivity. The collimated output beam from the QCL simplifies multi-reflection cells for vapor detection while also enabling large standoff distances. Results obtained by the QCL system indicate that <1 ppm for vapors can be achieved with specificity in a measurement time of seconds, and the QCL system was successfully able to detect agents in the presence of interferents.

QCLs provide additional capabilities for the dismounted warfighter. Given the relatively low power consumption, small package, and instant-on capability of the QCL, a handheld device can provide field teams with early detection of toxic agents and energetic materials in standoff, vapor, or aerosol form using a single technology and device which makes it attractive compared other technologies.

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8374-23, Session 6

A time-resolved 128x128 SPAD camera for laser Raman spectroscopy

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In continuous wave (CW) Raman spectroscopy, significant background fluorescence often overwhelms the Raman signature. A time-resolved Raman spectrometer offers significant background reduction based on the temporal difference between Raman signature and large background fluorescence. However, such instruments require highly sensitive, high speed detectors such as intensified charge coupled devices (iCCDs) or streak cameras. Thus, time-resolved Raman spectroscopy has not been used commercially due to cost, size, and complexity.

In this paper we present a time-gated, single-photon avalanche diode (SPAD) array, the first of its kind to be integrated with a time-resolved laser Raman spectrometer. Time-resolved Raman spectra from various highly fluorescent minerals were successfully observed which were impossible to identify with traditional CW Raman spectroscopy. The proof-of-concept system has photon detection efficiency (PDE) of 5 % at 5 V excess bias. The dark count rate (DCR) of this SPAD is 1.8 KHz at 5V excess bias. However, thanks to the nanosecond scale time-gating, noise rate per frame was suppressed down to ~10-3 counts at 40 KHz laser repetition rate. The SPAD imager has various advantages compared to a traditional photocathode-based imager system, such as smaller size, lighter weight, lower operation voltage, less power dissipation, and greater radiation hardness. These valuable features will help us to develop portable, fully automated, time-resolved single-photon detectors. The integration of this detector with a Raman instrument can provide enhanced capability in various fields such as mineralogy, archaeology, medical science, and planetary science, where rapid and non-destructive material identification on a microscopic scale is required.

8374-24, Session 6

Identification of targets at remote distances with Raman spectroscopy

R. Cox, B. Williams, M. Harpster, DeltaNu (United States)

We will demonstrate results for portable stand-off Raman systems for identification of high energy materials, and other threatening targets. The first system is a handheld 785 based system with distance capabilities from 0.3 to 3 meters. The second system is a larger tripod mounted system based on 1064 nm laser excitation that measures distances from 10 to 30 meters. This system is a pulsed and gated system that can be used for daylight operation (solar blind), and is less influenced by background fluorescence.

8374-25, Session 6

Fiber-optic Raman probe based on single-crystal sapphire fiber

M. Han, C. Raml, D. R. Alexander, X. He, Y. Lu, Univ. of Nebraska-Lincoln (United States)

Fiber-optic Raman probes are attractive in many applications such as in vitro medical applications because of their ability to hard-to-access environments and the lack of a need of optical alignment. However, a long-recognized problem of traditional glass-fiber-based Raman probes based is the large and broad background Raman signal generated by the fiber itself which can often overwhelm the Raman signal from the analyte. We develop a novel fiber-optic Raman probe based on single-crystal fibers that can overcome the problem. Due to the crystalline structure, single-crystal sapphire fiber features several narrow bandwidth peaks in its Raman spectrum with very low Raman signal elsewhere. Using a number of samples, we demonstrate that a Raman probe based on a 50cm long, 200μm diameter sapphire fiber exhibits much higher signal-to-noise ratio than a probe based on a glass fiber with similar length. Surface enhancement techniques are also being investigated for the sapphire fiber Raman probe.

8374-26, Session 6

Portable Raman spectroscopy using retina-safe (1550 nm) laser excitation

S. R. Farquharson, Real-Time Analyzers, Inc. (United States)

During the past decade, the use of portable Raman analyzers to identify unknown substances in the field has grown dramatically. Often, measurements require the laser beam to exit the confines of the sample compartment, which increases the potential of eye or skin damage. This is especially true for most commercial analyzers, which use 785 nm laser excitation. To overcome this safety concern, we have built a portable FT-Raman analyzer using a 1550 nm retina-safe excitation laser. Excitation at 1550 nm falls within the 1400 to 2000 nm retina-safe range, so called because the least amount of damage to the eye occurs in this spectral region. In contrast to wavelengths below 1400 nm, the retina-safe wavelengths are not focused by the eye, but are absorbed by the cornea, aqueous and vitreous humor. Here we compare the performance of this system to measurements of explosives at shorter wavelengths, as well as its ability to measure surface-enhanced Raman spectra of several chemicals, including the food contaminant melamine.

8374-27, Session 6

Fluorescence emission-excitation matrix and cavity ring-down spectroscopy of hydrocarbon oils and fuels

H. Omrani, Queen's Univ. (Canada) and GasTOPS Ltd. (Canada); A. E. Dudelzak, GasTOPS Ltd. (Canada) and Queen's Univ. (Canada); H. Loock, H. Waechter, Queen's Univ. (Canada)

Gas turbines, diesels and other heavy-machinery engines are omnipresent in today's society. Their efficiency and safety strongly depend on the condition of the lubricants and fuels that are vitally necessary to operate the machinery. During storage, transportation and operations these - typically complex hydrocarbon - substances suffer from contamination and wear, i.e. chemical/molecular-structure transformation. Left unmonitored/uncontrolled, these processes could lead to failures of the important liquid components of the machinery and, eventually, to extensive damage or failure - often catastrophic - of the machine. Surprisingly, there exist not a single commercially available sensor that could reliably monitor in real time chemical or structural conditions of lubricants and fuels used in or supplied to the engines.

This work is aimed at exploring the potential of the optical absorption, multi-wavelength induced excitation-emission matrix (EEM) fluorescence, and cavity ring-down (CRD) spectroscopies for developing a representative spectroscopic indicator of the degradation-caused chemical and structural changes in certain hydrocarbons. Optical absorption, EEM, and CRD spectral signatures have been experimentally obtained for pure, and degraded/contaminated samples in a broad spectral range from UV to IR. EEM and CRD measurement concepts and prototype instrumentation sensors have been developed using both the distributed-component and fiber techniques. Quantitative limits of detection (LOD) of contaminants have been assessed for a number of types of fuels and lubricants. Application of an advanced computational algorithm and a software based on it for the confident real-time processing of the analytical spectroscopic data has been investigated.

8374-28, Session 6

Industrial Raman mapping spectroscopy for mining applications

M. De Biasio, R. Leitner, T. Arnold, A. Tortschanoff, G. McGunnigle, Carinthian Tech Research AG (Austria); N. Fietz, L. Weitkämper, RWTH Aachen (Germany); D. Balthasar, V. Rehrmann, TITECH GmbH (Germany)

Raman spectroscopy can be applied to almost any bio-molecules. If a sample is lit with monochromatic laser light, most of the light is elastically scattered (Rayleigh scattering) with no change in photon energy (or frequency). However, a small portion of the scattered light is inelastically scattered (Raman scattering) with a corresponding shift in frequency. This fraction of the reflected light provides information about the vibrations of molecules. The difference between the incident and scattered frequencies is due to an excitation of the molecular system. A Raman spectrum is obtained, by measuring the intensity of the scattered photons as a function of the shift in frequency. These characteristic Raman peaks allow the spectroscopic separation of different molecules or identical molecules in different crystalline forms. Here, we demonstrate the feasibility of using a macroscopic industrial Raman mapping system for detecting and discriminating minerals such as dolomite, marble, calcite and pyrite. Test sets of mineral samples were taken from different mines and Raman spectra of the samples measured using the Raman mapping spectrometer. Characteristic spectral features were identified and used to build a chemometric model. Our experimental results show that it is indeed possible to detect and discriminate different minerals using a Raman mapping system. As the components used are also suitable for industrial conditions, we conclude that the technique offers a viable alternative to sensing methods currently used for sorting.

8374-30, Session 7

High-speed resonant FTIR spectrometer

J. Rentz Dupuis, D. Carlson, D. J. Mansur, S. P. Newbry, R. Vaillancourt, J. R. Engel, OPTRA, Inc. (United States); B. Engel, Nelson Air Corp. (United States)

OPTRA is in the process of completing the development of a high speed resonant Fourier transform infrared (HSR-FTIR) spectrometer in support of the Army's thermal luminescence measurements of contaminants on surfaces. Our system employs a resonant scanning mirror which enables 10 kHz spectral acquisition rate with 16 cm-1 spectral resolution over the 700 to 1400 cm-1 spectral range. To date this system represents the highest/broadest combination of spectral acquisition rate and spectral range available.

Our paper reports on the final design, build, and test of the HSR-FTIR spectrometer system. We present a final radiometric analysis predicting system performance along with the details of the signal channel conditioning which addresses the effects of the high speed sinusoidal scanning. We present the final opto-mechanical design and the high speed interferogram acquisition scheme. We detail the system build and integration and describe the tests that will be performed to characterize the instrument. Finally, we offer a list of future improvements as well as other applications for the HSR-FTIR system.

8374-31, Session 7

A new high-resolution, high-throughput HyperFlux spectrometer: first experience as applied to Raman spectroscopy

B. Schmidt, Arjae Spectral Enterprises Ltd. (Canada); J. Meade, B. Behr, A. Weinroth, Arjae Spectral Enterprises, Inc. (United States)

Dispersive spectrometers provide the advantage of capturing an entire spectrum in a single exposure, avoiding the need for moving parts such as in FTIR spectrometers and scanning monochrometers, and therefore are the technology of choice for high-speed applications. However, dispersive spectrometers have been fundamentally limited by the entrance slit, resulting in a trade-off between resolution and throughput efficiency.

A new class of dispersive spectrometers has been developed by Arjae Spectral Enterprises. These new devices incorporate a high-throughput "virtual slit" that eliminates the classic trade-off of resolution and throughput. The virtual slit is an étendue preserving device that increases the spectral resolution by narrowing the focused spot width while not blocking any of the light in its operation.

Since the new spectrometer from Arjae Spectral Enterprises does not waste any light it can detect up to 10x more signal than competing devices with the same resolution. This spectrometer has been used as an OEM component in a commercial Raman device to greatly increase its performance by shortening the integration time by a factor of 5x while also providing a 2x improvement in resolution. Other important application areas for this new spectrometer include forensics, standoff-Raman hyper-spectral imaging, and close proximity scanning.

The availability of high resolution, high throughput spectrometers open up new possibilities in high-speed and low light level spectroscopic applications because of their ability to achieve high resolution with no light loss.

8374-36, Session 7

Pulsed and high-speed FTIR spectroscopy

S. P. Heussler, National Univ. of Singapore (Singapore); H. O. Moser, Karlsruher Institut für Technologie (Germany); S. M. P. Kalaiselvi, C. Quan, C. J. Tay, M. Breese, National Univ. of Singapore (Singapore)

Fourier transform interferometry (FTIR) is the uncontested workhorse of infrared spectroscopy, in particular, in the fingerprint range of molecules (400-4000 cm-1). There are widespread applications to chemical analysis, forensics and homeland security [1], low energy electron excitations in condensed matter, and metamaterials [2,3]. Commonly performed by means of mechanically scanning interferometers such as a Michelson with one scanning mirror, its capability of measuring fast signals is limited.

We present a multi-channel FTIR spectrometer (MC-FTIR) that is capable of single-shot operation no matter how short the single pulse is, provided it delivers sufficient photons for the signal to overcome the noise [4]. It can capture fast transient signals, limited again by the signal-to-noise ratio and data transfer rate of the detector. Our device is based on a micro/nanomanufactured 3D multimirror array (MMA) which allows collecting a whole interferogram simultaneously. MMAs are manufactured by means of a patented multiple moving mask grey-level deep X-ray lithography process. Up to 640 mirror cells, generating optical path differences from 0 to about 1 mm, were achieved so far at optical quality. We have demonstrated sub-millisecond pulses and a spectral resolution of 10 cm-1. The optical system is similar to a Czerny-Turner mount with the MMA replacing the grating and a MCT focal plane array (FPA) capturing the interferogram.

Our MC-FTIR enables extension of FTIR-based IR spectroscopy to arbitrarily short pulses and to fast transient signals. As the optical

system is small and rugged, the instrument lends itself readily to field applications. Ongoing work is aimed at emerging applications including biomedical, laser-induced breakdown spectroscopy, and spectroscopy of synchrotron radiation.

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8374-29, Session 8

Fourier transform, infrared-phase-shift cavity-ring-down spectrometer

J. Rentz Dupuis, J. R. Engel, OPTRA, Inc. (United States)

OPTRA has developed a novel approach to phase shift cavity ring down spectroscopy (PS-CRDS) using a Fourier transform infrared (FTIR) modulator to impose the spectrally-dependent amplitude modulation on a broadband IR light source. As with previous PS-CRDS measurements, we excite a resonant cavity with amplitude modulated energy and measure the phase shift of the modulated signal exiting the cavity which is proportional to the ring down time and inversely proportional to the losses of the cavity including molecular absorption. In contrast to previous efforts, we impose the amplitude modulation with the FTIR interferometer instead of an external electro-optical modulator and extract the phase from each interferogram thereby enabling broadband FTIR-PS-CRDS measurements at greater than 1 Hz update rates. The measured phase spectra can then be used for multicomponent analysis. The combined measurement can be viewed as a resonant cavity enhancement to traditional FTIR spectroscopy or a broadband enhancement to CRDS.

In our paper we present the theory behind this measurement and describe the breadboard and test results from our feasibility study.

8374-32, Session 8

Realization of a hybrid-integrated MEMS scanning grating spectrometer

T. Pügner, H. Grüger, J. Knobbe, H. Schenk, Fraunhofer-Institut für Photonische Mikrosysteme (Germany)

Spectrometers and Spectrographs based on scanning grating monochromators are well established tools for various applications. As new applications came into focus in the last few years, there is a demand for more sophisticated and miniaturized systems. The next generation spectroscopic devices should exhibit very small dimensions and low power consumption, respectively. We have developed a spectroscopic system with a volume of only (15 x 10 x 14) mm³ and a few milliwatts of power consumption that has the potential to fulfill the demands of the upcoming applications. Our approach is based on two different strategies. First we apply resonantly driven MEMS (micro electro mechanical systems). The latest generation of our MEMS scanning grating device has two integrated optical slits and a piezoresistive position detection in addition to the already existing miniaturized 1-d scanning grating plate and the electrostatic driving mechanism. Our second strategy is to take advantage of the hybrid integration of optical components by highly sophisticated manufacturing technologies. One objective was the combination of MEMS technology and a planar mounting approach, which facilitate the mass production of spectroscopic systems and a significant reduction of cost per unit. We present the optical system design as well as the realization of a miniaturized scanning grating spectrometer for the near infrared (NIR) range between 950 nm and 1900 nm with a spectral resolution of 10 nm. The MEMS devices as well as the optical components have been manufactured and first samples of the spectroscopic measurement device have been mounted by an automated sub-micron die bonder. High volume production along with an optional wafer assembly will be subject to future developments. The miniaturized MEMS spectrometer can serve a wide variety of established and new applications.

8374-33, Session 8

Widely tunable, Fabry-Perot-filter-based MWIR and LWIR microspectrometers

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As is generally known, miniature infrared spectrometers have great potential, e. g. for process and environmental analytics or in medical applications. Many efforts are made to shrink conventional spectrometer concepts, such as FTIR or grating spectrometers. A more rigorous approach to highly miniaturized devices is the use of MEMS technologies. The hybrid integration of a micromechanical Fabry-Perot filter in a pyroelectric detector results in very compact, robust and cost effective microspectrometers.

Based on an established technology for the mid wave infrared range (3...5 µm) new filter and sensor designs with expanded spectral ranges have been developed within the last years, especially for the long wave infrared region. For these purpose a new thin film material system based on three different layers (L, M, H) has been introduced to reduce internal stress in the reflector layer stack and to extend the optical design flexibility. FP filters for the spectral range of 5.5...8 µm are particularly suited for the analysis of liquids, e. g. in the chemical industry. A dual-band filter, which can be simultaneously tuned in two spectral bands (4...5 µm & 8...11 µm) has been specifically designed to monitor anesthetics and carbon dioxide in the human breath. Good results in terms of spectral bandwidth (≥ 80 nm) and finesse (≤ 60) could be demonstrated. The dual-band spectrometer module is based on a two-channel pyroelectric detector in a TO8 housing. Channel separation is realized by means of an integrated dichroic beamsplitter.

8374-34, Session 8

A compact optical spectrometer based on a single-grating Fresnel diffractive optical element

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The optical spectrometer, despite a steady progress in performance and function, is typically bulky due to the use of multiple discrete optical components. However, with the rapidly developing portable electronics field and emerging lab-on-a-chip technologies, there exists a growing desire to miniaturize spectrometers. Previous efforts to reduce the size of spectrometers have included the use of curved gratings and volume holograms. Recently, we have demonstrated a hybrid diffractive optical element that combines the dispersion function of a grating and the focusing function of a Fresnel lens into a single device (G-Fresnel) fabricated by PDMS soft-lithography. Additionally, the G-Fresnel device promises a low f-number enabling compactness of the system while maintaining high spectral resolution, and has surface-relief patterning which can potentially be volume-produced through replicating, significantly reducing developmental costs. We have explored the use of the G-Fresnel device in an optical spectrometer both theoretically and experimentally. Our simulation shows that a spectral resolution of ~1 nm can be achieved by the G-Fresnel with aperture diameter and focal length of only 4 mm and 1 cm, respectively. A proof-of-concept G-Fresnel-based spectrometer is also demonstrated, yielding sub-nanometer resolution. With further improvements, a G-Fresnel based spectrometer has the potential for use in mobile platforms such as lab-on-a-chip microfluidic devices and other mobile spectrometer applications.

8374-35, Session 8

Compact, low-cost waveguide-based optical spectrometer for detection of chemical/biological agents

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Conventional optical spectrometers that are based on bulk optical components tend to be relatively large and expensive compared to the other components used in systems used for detecting chemical/biological agents. These spectrometers use discreet components to focus and disperse the light. Each component must be individually fabricated and then aligned in the instrument. This can be labor intensive, difficult to scale, and relatively expensive. Micro-spectrometers based on focusing waveguide gratings incorporate both spectral dispersion and focusing functions into a single component. This leads to a more compact design and fewer assembly steps. While previous fabrication efforts concentrated on using electron beam lithography to pattern the waveguide gratings, we demonstrate that these gratings can be replicated at the wafer level using nano-imprint lithography (NIL). Hundreds of devices can be fabricated on a single wafer using NIL, making the focusing waveguide grating based spectrometer a truly scalable technology that could be less expensive than current solutions.

In addition, waveguide based spectrometers are ideal for integration into micro-fluidic systems because of their planar format. By locating the sample at the surface of the waveguide core, the signals can be directly coupled into the spectrometer without the need for external connections. The design of the spectrometer also makes it relatively simple to probe multiple, spatially separated samples with a single device, providing a platform for multiplexed chemical/biological sensors.

In this paper we present preliminary data from a prototype system using a planar waveguide based micro-spectrometer and explore potential applications for these devices.

8374-37, Session 8

Characterization of materials using infrared photothermal microspectroscopy

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There is a need for new characterization techniques that can map the chemical composition with a 1-10 micron spatial resolution. Established imaging techniques at the nanometer scale are often impractical at the micron-scale. The emerging technique of Raman micro-spectroscopy provides adequate spatial resolution (~1 micrometer), but may not always be useful due to its low throughput and for samples with strong fluorescence. We are developing a new non-contact, non-destructive characterization tool that involves photo-thermal heating of the sample with quantum cascade lasers (or other suitable infrared lasers) and measuring the resulting increase in thermal emission by an infrared detector. Since the thermal emission signal from the surface is directly proportional to the absorbed laser energy which is in turn proportional to the absorption coefficient, by tuning the wavelength of the laser we directly measure the infrared spectrum of the sample. By raster-scanning we obtain chemical composition maps at ~10 micron spatial resolution. We discuss a modification to the instrument that allows the spatial resolution to increase from the infrared far-field diffraction limit (~10 microns) to ~1 micron.

8374-38, Session 8

Micromechanical photothermal spectroscopy of trace gases

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The need to accurately detect chemical or biological agents and toxic industrial chemicals (TICs) for national defense and homeland security using inexpensive, miniature sensors remains a challenge. Here, we describe a new method to spectroscopically detect trace gases using optical micromechanical systems coated with sorbent materials. This method, Micromechanical Photothermal Spectroscopy (MPS), combines a tunable mid-infrared source, a bimaterial microbridge, microcavity interferometry, and functionalized sorbent polymers to detect molecular vapor-phase analytes. Our bimaterial micromechanical structures are fabricated using gold and benzocyclobutene (BCB). Upon exposure to tunable mid-infrared radiation and a target molecular analyte, the functionalized bimaterial microbridge absorbs these molecules and heats up at infrared wavelengths that correspond to rotational or vibrational molecular resonances. This heating results in bending of the microbridge, which is read-out using microcavity interferometry. The molecular sorption is reversible, enabling continuous monitoring with no electrical power required at the sensor. In this talk, we will show that the measured infrared spectra of a number of analytes obtained using MPS are similar to existing FTIR spectra, discuss detection and temporal response limits, and compare measurements to calculations from our finite-element thermal-mechanical model. We believe that MPS represents an important advance in trace-grace sensing since it does not require a mid-IR detector, requires no electrical power at the sensor, is inherently miniature and low-power, and provides a signature-based spectral response of the adsorbed analyte at ultra-low vapor concentrations.

8374-39, Poster Session

Snapshot spectral imaging using optimised computer generated holograms

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Breast cancer is detected and staged manually by experienced pathologists using fluorescence microscopy. A common problem with multi-color fluorescently labelled preparations is the crosstalk between the channels caused by the overlap of the emission spectra of the different fluorescent dyes. A hyper-spectral imaging system in combination with sophisticated image processing algorithms can significantly reduce the spectral crosstalk and help pathologists in this task.

The classical approach to acquire hyper-spectral data is to sequentially scan a sample either spatially or over wavelength. With a computed tomography imaging spectrometer (CTIS) it is possible to acquire two spatial dimensions and a spectral dimension during a single integration time, without scanning in either spatial or spectral dimensions. The presented CTIS system uses instead of two crossed glass gratings, which are optimised for a single wavelength, an optimised computer generated hologram (CGH) to project the spectral and spatial image information simultaneously onto a 2D CCD camera array. Reconstruction algorithms are used to reconstruct the 3D hyper-spectral dataset from the acquired 2D images. After spectral unmixing and the spectral classification, hidden Markov Models are used to exploit the spatial context of the acquired images to increase the sensitivity and specificity of the spectral classification.

The current system is designed for a microscopy application for the analysis of fixed specimens in pathology and cytogenetics, cell imaging and material analysis. The CTIS approach is not limited to microscopy applications and it would be possible to implement it in a hand-held device e.g. real-time, intra-surgery tissue classification.

8374-40, Poster Session

NO and N2O detection employing cavity enhanced technique

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At present, it can be identified two main factors to explore new methods and technologies aimed at the development of finer sensors for trace detection of chemicals. Firstly, it is a desire to better understand the world around us and the universe. Secondly, to ensure broad sense of safety, i.e., prevent or minimize the threat level environment, health and life of humans, and defence and national security

The article describes an application of cavity enhanced absorption spectroscopy in nitric oxide and nitrous oxide detection system. Both oxides are important greenhouse gases that have a large influence on environment, living organisms and human health. For instance, these compounds are biomarkers some human diseases, determine the level of acid rain, and characterize specific explosive materials. Therefore these gases monitoring is of great importance for various applications: from routine air monitoring in industrial area and regions of intensive traffic, in detection of explosives at airports, finally in medicine investigation, for health care, etc.

The developed detection system is able to measure both NO and N2O concentration at ppb level. Its sensitivity is comparable with sensitivities of instruments basing on other methods, e.g. gas chromatography or mass spectrometry. The system can be applied to control the atmosphere quality. Moreover, detection of vapours from some explosive materials is also possible. Some successful research with nitro-glycerine, nitrocellulose, and TNT has been already performed.

8375-01, Session 1

What are single photons good for?

H. Zbinden, Univ. of Geneva (Switzerland)

This conference is about photon counting and its applications. In the last 10 years novel applications in the field of quantum optics and quantum information processing and communication (QIPC), in particular in quantum cryptography have been drawing a lot of interest. Moreover, new tools like single photon sources, entangled photon pair sources or photon number resolving detectors have appeared.

In this talk, we discuss which tools are actually useful for QIPC and hope to stimulate some thoughts about new applications for these tools. We do this by reviewing some recent activities of our group. These activities go from the applied side of high speed QKD, single photon detectors and quantum metrology to more and more futuristic concepts, such as quantum repeaters, qubit amplifiers and device independent QKD. In particular, we will show that single photon sources are not as useful for QKD as one might expect, but they have real advantages for some other quantum protocols.

8375-02, Session 1

Novel photon detection technologies for quantum communications

M. Sasaki, National Institute of Information and Communications Technology (Japan)

We present the latest results on two kinds of photon detectors: single photon detectors (SPDs) and photon number resolving detector (PNRD). We developed high speed and low noise SPDs using superconducting nano-wire (abbreviated by SNSPD) and semiconductor (InGaAs) avalanche photo-diode (APD). The SNSPD system has totally four channels all of which have the detection efficiency higher than 16% at 100Hz dark count rate. The InGaAs APD system also has four channels and the best performance is represented by the after-pulse probability of 0.61%, the dark count probability of 0.71 ´10–6 (~1kHz), and the detection efficiency of 10.9%. Both systems were applied to wavelength division multiplexing quantum key distribution (WDM-QKD) operated at 1.2GHz repetition rate in a field environment. The PNRD is made of superconducting transition edge sensor. It was applied to the implementation of quantum receiver which could beat the homodyne limit of the bit error rate of binary coherent states. We discuss future perspective of quantum communications with those photon detection technologies, including multi-user QKD networks and low-power high capacity communications.

8375-03, Session 1

Quantum random number generators and their use in cryptography

M. Stipcevic, Univ. of California, Santa Barbara (United States) and Rudjer Boskovic Institute (Croatia)

Random number generators (RNG) are an important resource in many areas: cryptography (both quantum and classical), probabilistic computation (Monte Carlo methods), numerical simulations, industrial testing and labeling, hazard games, scientific research etc. Because today's computers are deterministic, they can not create random numbers unless complemented with a RNG. Randomness of a RNG can be defined and scientifically characterized and measured. Especially valuable is the information-theoretic provable RNG (True RNG - TRNG) which, at state of the art, seem to be possible only by use of physical randomness inherent to certain (simple) quantum systems. On the other hand, current industry standards dictate use of RNGs based on free running oscillators (FRO) whose randomness is derived from electronics noise present in logic circuits and which cannot be strictly proven. This approach is currently used in 3-rd and 4-th generation FPGA and ASIC hardware, unsuitable for realization of quantum TRNG. We compare weak and strong aspects of the two approaches and discuss possibility of building quantum TRNG on a chip level. Finally, we discuss several examples where use of a TRNG is critical and show how it can significantly improve security of cryptographic systems.

8375-04, Session 1

Reliable source of conditional states by multiple-photon subtraction using hybrid photodetectors

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The possibility of using optical fields in applicative protocols depends on the capability of generating and manipulating optical states that are robust with respect to losses (i.e. that contain a sizeable number of photons) and that can be produced and addressed at high rate.

For all these reasons, mesoscopic ps-pulsed optical states containing up to few tens of photons per pulse seem to be the ideal candidates for applications to quantum communication protocols in which each pulse must be addressed individually.

By using hybrid photodetectors (Hamamatsu) we have exploited the photon-number correlations existing in bipartite optical states to demonstrate the effect of multiple-photon subtraction on the generation of conditional states in the pulsed regime.

We operated on both classical and quantum Gaussian bipartite states in the mesoscopic regime without background subtraction and without the need of corrections. The obtained conditional states are non-Gaussian in nature, thus particularly useful for applications in Quantum Information. In fact, non-Gaussian states and operations have been studied in connection with entanglement distillation, teleportation, cloning and quantum storage.

As a further step towards the generation of non-Gaussianity as a resource, we also measured the effect of conditioning on originally non-Gaussian bipartite states produced by using a beam splitter acting on a displaced phase-averaged coherent state.

All the experimental results are in excellent agreement with theoretical models.

8375-05, Session 2

Near-unity efficiency, single-photon sources based on tapered photonic nanowires

J. Bleuse, M. Munsch, J. Claudon, Commissariat à l'Énergie Atomique (France); N. Gregersen, J. Mørk, Technical Univ. of Denmark (Denmark); N. S. Malik, E. Dupuy, J. Gérard, Commissariat à l'Énergie Atomique (France)

Single-photon emission from excitons in InAs Quantum Dots (QD) embedded in GaAs Tapered Photonic Wires (TPW) already demonstrated a 0.72 collection efficiency, with TPWs where the apex is the sharp end of the cone [1]. Going to alternate designs, still based on the idea of the adiabatic deconfinement of the quasi-Gaussian emission mode, but with inverted TPW where the diameter, along a 20-μm length, goes from 200 nm close to the base mirror to 1.5 μm at the exit facet, leads to even larger efficiencies, above 0.8 and close to the computed value of 0.89 [2]. In addition, these inverted TPWs make the electric pumping of the emitters compatible with these large efficiencies.

[1] J. Claudon, J. Bleuse, N. S. Malik et al., Nat. Phot. 4, 174 (2010).

[2] N. Gregersen, T. R. Nielsen, J. Mørk et al., Opt. Exp. 18, 21204 (2010).

8375-06, Session 2

Efficient extraction, frequency conversion, and amplitude modulation of single photons from epitaxially grown quantum dots

K. Srinivasan, National Institute of Standards and Technology (United States)

Isolated quantum emitters such as single epitaxially-grown InAs/GaAs quantum dots are potentially bright, stable, and scalable triggered single photon sources for various quantum communication and information processing tasks. In this talk, I will outline our laboratory's efforts to develop these structures. One line of research involves the use of nanophotonic structures to improve the collection efficiency of emitted photons by over an order of magnitude in comparison to quantum dots in bulk GaAs. Circular grating microcavities provide radiative rate enhancement and vertical light extraction into a near-Gaussian far-field over a moderate spectral bandwidth, while suspended channel waveguides are evanescently coupled to optical fiber taper waveguides to provide direct and broadband extraction of single photons into a standard single mode optical fiber. A second line of research is focused on manipulating the frequency of quantum dot single photons after they have been generated, for applications in hybrid quantum systems in which disparate quantum systems operating at different frequencies must be interfaced. Quasi-phase-matched sum frequency generation is used to convert telecommunications-band photons to the visible. Photon correlation measurements confirm that the converted signal is still dominantly composed of single photons, and can be detected more effectively now that the wavelength is within the detection window of silicon (rather than InGaAs) single photon counters. Finally, we are investigating approaches for modifying the temporal shape of the single photon pulses. Direct electro-optic amplitude modulation and nonlinear frequency conversion using a fast pulsed laser are used to gate the exponentially-shaped waveforms associated with spontaneous emission from a quantum emitter with a 1.5 ns lifetime to modulated waveforms (including Gaussian-shaped pulses) at 350 ps timescales.

8375-07, Session 3

High-throughput, single-molecule analysis with a multipixel SPAD array

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Single-molecule Förster resonance energy transfer (smFRET) is a powerful tool for extracting distance information between two fluorophores (a donor and acceptor dye) on a nanometer scale. This method is commonly used to monitor binding interactions or intra- and intermolecular conformations in biomolecules freely diffusing through a focal volume or immobilized on a surface.

The diffusing geometry has the advantage to not interfere with the molecules and to allow sampling of a large number of distinct individual molecules. However, to allow separating photon bursts from individual molecules requires low concentrations. This leads to long acquisition times (minutes to hours) in order to obtain sufficient statistics. It also prevents from studying dynamic phenomena happening on time scales larger than the burst duration but smaller than the acquisition time. Parallelization of acquisition overcomes this limit by increasing the acquisition rate while keeping the same low concentrations required for individual molecule burst identification.

In this work we present a realization of this idea using multispot excitation and detection. The donor excitation spots are created by a LCOS spatial light modulator while fluorescent emission of donor and acceptor dyes is collected and refocused on a custom 8-pixel SPAD array. smFRET measurements were performed on various DNA samples synthesized with various distances between the donor and acceptor fluorophores and compared with results obtained with a conventional single-spot acquisition approach.

Identical results obtained with shorter acquisition time demonstrate the potential of this approach for high-throughput smFRET analysis on freely diffusing molecules.

8375-08, Session 3

Functional analysis of fiber optic sensors using statistical photon counting: an automobile case study covered from quantum mechanics

J. A. Betancur Ramírez, Univ. EAFIT (Colombia)

Currently, the applications of fiber optic sensors on the automobile industry are gaining importance due to their potential for implementation in data acquisition and signal transmission. This paper covers from quantum mechanics, the photon counting in optical fibers using coherent states and generalized intelligent states, described by hyper-geometric functions and Bessel functions. Different fiber optic configurations will be analyzed, in order to expose the most representative factors that influence the probability of coherent and intelligent photons detected and transmitted by optical fibers. Then, from the automotive industry, some applications are presented, from which the quantum-optical approach here proposed makes sense. Finally, we present some topics for future research in the field of photon counting applied to fiber optic sensors.

8375-09, Session 3

Time-sequential binary sensing for high-dynamic range imaging

Y. M. Lu, Harvard Univ. (United States)

Before the advent of digital image sensors, photography, for the most part of its history, used film to record light information. At the heart of every photographic film are a large number of light-sensitive grains of silver-halide crystals. During exposure, each micron-sized grain has a binary fate: Either it is struck by some incident photons and becomes "exposed", or it is missed by the photon bombardment and remains "unexposed". In the subsequent film development process, exposed grains, due to their altered chemical properties, are converted to silver metal, contributing to opaque spots on the film; unexposed grains are washed away in a chemical bath, leaving behind them transparent regions on the film. Thus, in essence, photographic film is a binary imaging medium, using local densities of opaque silver grains to encode the original light intensity information. Thanks to the small size and large number of these grains, one hardly notices this quantized nature of film when viewing it at a distance, observing only a continuous gray tone.

In this work, we study a new digital image sensor that is reminiscent of photographic film. Each pixel in the sensor has a binary response, giving only a one-bit quantized measurement of the local light intensity. At the start of the exposure period, all pixels are set to 0. A pixel is then set to 1 if the number of photons reaching it during the exposure is at least equal to a given threshold q. We formulate the binary sensing scheme as a parameter estimation problem based on quantized Poisson statistics, and study the optimal time-sequential threshold selection strategy to minimize the mean squared errors of the estimation within a fixed observation time window. Numerical results verify our theoretical analysis and demonstrate the effectiveness of our image reconstruction algorithm. They also suggest that the proposed time-sequential binary sensing scheme can have substantially higher dynamic ranges than traditional sensors, making it particularly attractive in acquiring scenes containing both bright and dark regions.

8375-10, Session 4

Photon counting laser radar

D. G. Fried, MIT Lincoln Lab. (United States)

Photon counting technology has enabled the fielding of airborne laser radar (ladar) systems that rapidly collect 3D terrain maps from standoff altitudes of 4-6 km with modest laser powers (e.g. 1.5 W). In the photon counting regime only a few detected photons (5-10 on average) are required to reliably estimate the height of the ground surface at each spatial resolution element, thereby minimizing laser power requirements. Additionally, when the signal from the single photon detection event is large (as is the case for Geiger-mode operation), the readout timing circuitry is simple and compact, allowing fabrication of large arrays of single photon detectors, each independently measuring photon time-of-arrival. The large array is placed at the focal plane of an imaging system to create a 3D camera, typically with nanosecond timing resolution. The large number of detectors and high frame rate allows rapid collection of 3D imagery.

This paper will address system-level considerations for airborne photon counting ladar systems and use as example the Airborne Ladar Imaging Reseach Testbed (ALIRT). Recent upgrades enable that system to record time-of-arrival signals for up to 6×10^7 photons/second (1064 nm), with system range resolution of 20 cm FWHM. The system flies on a business jet, and is able to produce wide-area 3D terrain maps from 6 km above ground level with 30 cm ground spatial resolution at typical instantaneous area collection rates of 300 km^2/hour. Straightforward scaling using existing laser and detector technology will enable systems that collect 50 cm resolution 3D imagery from 12 km altitude at rates approaching 10^4 km^2/hour.

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8375-11, Session 4

Photon counting lidar activities at FOI in Sweden

O. Steinvall, L. J. Sjöqvist, M. Henriksson, Swedish Defence Research Agency (Sweden)

Photon counting techniques using direct detection has recently gained considerable interest within the laser radar community. The high sensitivity is of special importance to achieve high area coverage in surveillance and mapping applications and long range with compact systems for imaging, profiling and ranging. New short pulse lasers including e.g. the super continuum laser is of interest for active spectral imaging. A special technique in photon counting is time-correlated single photon counting (TCSPC). This technique can be utilized together with short pulse (pico second) lasers to achieve very high range resolution and accuracy (millimeter level). Low average power lasers in the milliwatt range enables covert operation with respect to present laser warning technology.

By analyzing the return waveform range and shape information from the target can be extracted. By scanning the beam high resolution 3D images are obtained. At FOI we have studied the TCSPC with respect to range-profiling and imaging. Limitations due to low SNR and dwell times are studied in conjunction with varying daylight background and atmospheric turbulence. Examples of experimental results will be presented and discussed with respect to some system applications.

8375-12, Session 4

Geiger-mode APD camera system for single-photon 3D ladar imaging

M. Entwistle, M. A. Itzler, J. Chen, M. Owens, K. M. Patel, X. Jiang, K. Slomkowski, S. Rangwala, Princeton Lightwave, Inc. (United States)

The unparalleled sensitivity of 3D LADAR imaging sensors based on single photon detection provides substantial benefits for imaging at long stand-off distances and minimizing laser pulse energy requirements. To obtain 3D LADAR images with single photon sensitivity, we have demonstrated focal plane arrays (FPAs) based on InGaAsP Geiger-mode avalanche photodiodes (GmAPDs) optimized for use at either 1.06 um or 1.55 um. These state-of-the-art FPAs exhibit excellent pixel-level performance and the capability for 100% pixel yield on a 32 x 32 format. To realize the full potential of these FPAs, we have recently developed an integrated camera system providing turnkey operation based on FPGA control. This system implementation enables the extremely high frame-rate capability of the GmAPD FPA, and frame rates in excess of 250 kHz (for 0.4 us range gates) are accommodated using an industry-standard CameraLink interface in full configuration. Range gate durations spanning 4 ns to 10 us provide broad operational flexibility. The camera also provides real-time signal processing in the form of multi-frame gray-scale contrast images and single-frame time-stamp histograms. Gray-scale images can be acquired over any specified number of frames and are delivered interleaved with raw time-of-flight frame data. Range histograms are computed for every frame, and the user-selectable coarse-grained range bin with the greatest number of pixel counts is included among the status information in the header row that accompanies every frame. Automated bias control has been implemented to maintain a constant photon detection efficiency in the presence of ambient temperature changes.

8375-13, Session 4

Low-power, 20 meter 3D ranging SPAD camera based on continuous-wave indirect time-of-flight

S. Bellisai, L. Ferretti, F. A. Villa, Politecnico di Milano (Italy); S. Tisa, Micro Photon Devices S.r.l. (Italy); A. Tosi, F. Zappa, Politecnico di Milano (Italy)

We present a 3D ranging camera based on a low-power LASER illuminator and continuous-wave indirect time-of-flight (iTOF) technique. The high sensitivity is provided by the sensor that is based on Single-Photon Avalanche Diode (SPAD) pixels, which ensure single-photon sensitivity and high frame rate operations (up to 100 fps). The overall system is low-power and cost-effective, being the sensor manufactured in a standard 0.35 μm CMOS process. The camera provides the distance information in real-time, by means of an on-board FPGA, with a range of 20 m and a depth resolution down to few centimeters.

8375-14, Session 5

An FPGA-based module for multiphoton coincidence counting

D. A. Branning, Trinity College (United States); M. Beck, Whitman College (United States)

We present a multi-channel coincidence-counting module for use with single-photon detectors. The module takes up to four TTL pulse inputs and counts either 2-, 3-, or 4-fold coincidences among them. Up to eight user-defined coincidence combinations can be assigned to different TTL outputs, which may be monitored externally. Each of these outputs also increments a corresponding counter on an onboard FPGA. The count values are delivered to a computer over a USB interface, and integrated under the control of custom LabVIEW software. Test results show that the modules can count regular pulse trains at up to 84 MHz with no losses, and that the coincidence-counting window can be made as short as 12 ns. Due to their low cost and small size, multiple modules can easily be combined to count arbitrary M-order photon coincidences among N inputs.

8375-15, Session 5

Recent advances in high-speed electronics for TCSPC and coincidence counting

G. Kell, D. Schulz, Fachhochschule Brandenburg (Germany); T. Roehlicke, H. Rahn, M. Wahl, PicoQuant GmbH (Germany)

Time-Correlated Single Photon Counting (TCSPC) with multiple detector channels is an invaluable tool in a growing range of vastly different disciplines. Applications are ranging from fundamental physics through single molecule spectroscopy, metrology, medicine and quantum information processing. However, existing instrumentation is often limited in its number of independent input channels. Solutions based on multiplexing several detectors into one timing channel provide input channels that are not truly independent, causing artifacts in correlation measurements and prohibiting multichannel coincidence correlation. On the other hand, dedicated hardware for pure coincidence correlation in some predefined time gate is limited to a small subset of applications. The most flexible technique overcoming these limitations is continuous time tagged recording of photon events on multiple synchronized channels. This allows coincidence correlation with picosecond accuracy as well as fluorescence lifetime measurements on multiple color or polarization channels, for instance in fluorescence lifetime imaging (FLIM). We present recent advances in concept and technology leading to new levels of performance. The key line of development we present is concerned with efforts of monolithic SiGe integration of parallel high speed Time-To-Digital Converters (TDC) towards shorter deadtime and scalability for many channels. The second line of work is aimed at overall throughput improvements. While USB 2.0 has made TCSPC data acquisition instruments portable and easy to use, it also imposed a throughput limit that becomes prohibitive in massively parallel time tagging applications. In order to overcome such limitations we have developed a new USB 3.0 host interface solution for our multichannel TCSPC devices.

8375-16, Session 5

Low-cost multichannel FPGA-based coincidence boards

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Field Programmable Gate Array (FPGA) technology has recently attracted attention from scientists who need highly versatile and reliable measurement and data processing devices because of their high flexibility and moderate cost. However, developing FPGA-based instruments from scratch can be a complex endeavor. In particular, FPGA-computer interfacing is often so burdensome that it becomes a significant barrier to developing such devices. Another difficulty arises from high jitter of single-photon detectors when combined with inherently random photon arrival times. We review recent efforts in making FPGA-based data handling devices and reducing said barrier. When an FPGA device is used to aid with data acquisition, interfacing with a computer-supported data bus becomes the most important issue. Fortunately, most of the issues associated with that need to be handled just once, i.e. a “platform” can be first built in such a way that only the “instrument” part needs tweaking when a next device is developed. We made such a platform that originally handles four digital inputs. The presented device can be easily modified to match user needs. FPGA firmware, computer driver software of this platform and their sources are available for a download from a NIST website.

8375-17, Session 5

4-channel, 20ps-resolution, monolithic time-to-amplitude converter for multichannel TCSPC systems

M. C. Crotti, I. Rech, I. Labanca, M. Ghioni, Politecnico di Milano (Italy)

Over the past years an always growing interest has arisen about the measurement technique of time correlated single photon counting (TCSPC) and many applications exploiting TCSPC have been developing in several fields such as medicine and chemistry. Moreover, the use of multianode PMT and of single photon avalanche diode arrays led to the development of acquisition systems with several parallel channels to employ the TCSPC technique in even more applications. Since TCSPC basically consists of the measurement of the arrival time of a photon, the most important part of an acquisition chain is the time measurement block, which must have high resolution and low differential nonlinearity, and in order to develop multidimensional systems, it has to be integrated to reduce both cost and area. We have designed and fabricated a 4 channel fully integrated time to-amplitude converter (TAC), built in 0.35 µm Si-Ge technology, characterized by a variable full scale range from 10 ns to 90 ns, very good time resolution (better than 20 ps FWHM), low differential nonlinearity (better than 0.04 LSB peak-peak and less than 0.2% LSB rms), high counting rate (16 MHz), low and constant power dissipation (50 mW) and low area occupation (340 × 390 µm2 per channel).

Moreover our measurements show a very little crosstalk between converters integrated on the same chip; this feature together with low power and low area make the fabricated converter suitable for parallelization, so it can be the starting point for future acquisition chains with a high number of parallel channels.

8375-18, Session 6

Superconducting nanowire single-photon detectors for optical communication and quantum information applications

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Single-photon detectors are a vital component for a wide variety of applications in fields ranging from quantum cryptography to biology and remote sensing. Superconducting nanowire single photon detectors (SNSPDs), which can have high efficiency, low noise, and excellent timing resolution, are fast becoming the detector of choice for some of these applications. Lincoln Laboratory has been developing these detectors for optical communication and quantum information applications, with a focus on increasing the detection efficiency and understanding the performance limitations of SNSPDs. Several such performance limitations arise when attempting to count at very high rates using SNSPDs. The kinetic inductance of the SNSPDs results in a recovery time that limits the maximum count rate and can effectively lower the detection efficiency at high count rates. Due to the shape of the efficiency recovery, determining the relationship between the input photon flux and the output rate can be non-trivial. In addition, at high count rates SNSPDs can also display a self-biasing effect due to feedback from the detector pulse, which effectively raises the bias current for the detector and can make the system unstable for certain types of readout circuits. Data demonstrating these effects and models that accurately fit the data will be discussed. Finally, ongoing work integrating SNSPDs into optical communications and quantum information applications will be presented.

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8375-20, Session 6

Enhancing the quantum efficiency of superconducting nanowire, single-photon detectors for near-infrared wavelengths

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The quantum efficiency of NbN and NbTiN superconducting nanowire single photon detectors drops with decreasing photon energy. We have taken different steps to improve this effect. We have fabricated a NbSi detector, which has a smaller superconducting gap (Tc is 2 K) than NbTiN or NbN (Tc is 15 K). We measure the detection efficiency for a wavelength range from 1100 to 1900 nm. In this range the NbSi detector shows a 10-fold increase in relative efficiency with respect to the NbTiN detector.

The fabrication of NbTiN detectors on an oxidized silicon substrate enables us to exploit constructive interference from the SiO2 - Si interface in order to achieve enhanced efficiency for NbTiN detectors. We have developed a practical fiber coupling method by etching the chip in the shape of the ferrule of an FC connectorized optical fiber. We achieve a system detection efficiency of >30% in the near infrared, which we confirm by an absolute efficiency measurement.

8375-21, Session 6

Fast path and polarisation manipulation of telecom wavelength single photons in waveguides using superconducting nanowire single-photon detectors

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Superconducting nanowire single-photon detectors (SNSPDs), offer sensitivity from visible to mid infrared with low dark counts and excellent timing resolution. These properties enable SNSPDs to be used in quantum information science and technology (QIST)[1]. Quantum waveguide circuits offer a scalable route to realizing photonic QIST on a chip [2, 3]. Characterization of quantum waveguide circuits using superconducting nanowire single-photon detectors has been demonstrated at λ = 804 nm [4].

In this demonstration, we switch to λ = 1550 nm which will allow the full range of telecommunication waveguide technologies to be exploited. We demonstrate fast polarization and path control of photons at 1550 nm in lithium niobate waveguide devices using the electro-optic effect [5]. We show fast switching of a two-photon entangled state at 4MHz. Using a lithium niobate polarization controller driven by two voltages, we manipulate the polarization of single photons to implement a feedback loop for robust quantum interference between two paths which interfere on a beam splitter. We demonstrate a bi-dimensional quantum interference pattern in the number of coincidental events recorded after the beam splitter as a function of the two driving voltages. Starting from random overlap in polarization between the two photons, we then use a gradient descent algorithm to iteratively choose the two applied voltages and demonstrate recovery of the quantum interference. These results point the way to a single platform that will enable the integration of nonlinear single photon sources and fast reconfigurable circuits for future photonic quantum information science and technology.

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8375-22, Session 6

Toward linear optical detection with single-photon sensitivity at telecom wavelengths

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Standard linear optical detectors have a maximum sensitivity in the few hundreds of photons range, limited by amplifier noise. On the other hand, single photon detectors, which are the most sensitive detectors, are strongly nonlinear: One or more photons result in the same output signal. Photon number resolving (PNR) detectors, which have the ability to discriminate the number of photons in a weak optical pulse, are of great importance in the field of quantum information processing and quantum cryptography. Moreover, a PNR detector with large dynamic range can cover the gap between these two detection modes. Such detectors are greatly desirable not only in quantum information science and technology, but also in any application dealing with low light levels.

In this work, we propose a novel approach to photon number resolving detectors based on spatial multiplexing of nanowire superconducting single-photon detectors. In the proposed approach, N superconducting nanowires, each connected in parallel to an integrated resistor, are connected in series. Photon absorption in a nanowire switches its bias current to the parallel resistor, forming a voltage pulse across it. The sum of these voltages, proportional to the number of absorbed photons, is measured at the output. The use of a cryogenic preamplifier with high input impedance for the read-out increases the linearity, the signal to noise ratio, and the speed. With this combination, we expect to be able to count few tens of photons with excellent timing resolution and very high sensitivity in the telecommunication wavelength range.

8375-23, Session 7

Silicon, single-photon avalanche diodes for high-performance, parallel-photon timing

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Thanks to the steady improvement in the detectors' performance, single-photon techniques are nowadays employed in a large number of applications ranging from single molecule dynamics to astronomy. In particular, silicon Single Photon Avalanche Diodes (SPAD) play a crucial role in this field thanks to their remarkable performance in terms of Photon Detection Efficiency (PDE), temporal response and Dark Count Rate (DCR). While CMOS technology allows the fabrication of large arrays of SPAD with built-in electronics, it is only resorting to custom fabrication processes that is possible to attain detectors with high-end performance required by most demanding applications. However, the fabrication of arrays for timing applications, even with a small number of pixels, is quite challenging with custom processes owing to electrical coupling between pixels.

In this paper we will discuss technological solutions for the fabrication of arrays of high-performance SPAD for parallel photon timing. The viability of such technologies will be demonstrated through a 32x1 SPAD array suitable for parallel operation at mega-count rate per channel.

8375-24, Session 7

Distortions from multiphoton triggering in a single CMOS SPAD

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Three methods for discriminating between single- and multi-photon triggering in a single CMOS Geiger-mode avalanche photodiode are compared. The first method, utilizing a measurement of the avalanche's quench time, correctly distinguishes between avalanches initiated by one expected photon or 100 expected photons with probability $p>0.80$ in single-shot measurements. The second method, which modulates the detector efficiency, correctly distinguished streams of 1-photon- or 100-photo-initiated avalanches with $p>0.95$, but is unable to provide a single-shot measurement. The final method, which examines distortions to the timing jitter, requires knowledge of the incident timing jitter a priori and is unlikely to be useful in most systems. All compared methods are independent of one another, and show promise for distinguishing how many photons seed an avalanche.

8375-25, Session 7

High-detection efficiency and picosecond timing compact detector modules with red-enchanced SPADs

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Commercially available photon counting modules provide either good timing resolution, down to a few tens of picoseconds, or excellent Photon Detection Efficiency (PDE) in red / near-infrared range. Conversely, many applications require that both these features are met simultaneously.

We present a compact photon timing module that fills the gap between high resolution and high detection efficiency systems. The module exploits Red Enhanced SPAD technology developed at Politecnico di Milano to attain a PDE as high as 40% at 800nm (peak of 60% at 600nm) while maintaining a temporal resolution of 100ps FWHM.

Simple operation and high performance are simultaneously achieved thanks to the incorporation of all the electronics needed to run properly the device. A fast active quenching circuit allows the operation of the detector up to 15Mcps, while the thermo-electric cooling system built-into the module guarantees a noise as low as a few counts per seconds for a 50µm diameter SPAD. A low-threshold avalanche pick-up circuit assures the stability of the temporal response; in particular, the shift of the peak's position is limited to a few picoseconds for operating frequencies ranging from a few counts per second to a few mega-counts per second. Moreover, 100ps timing resolution is achieved also with light diffused across the whole device active area thanks to the high uniformity of the fabrication process. Finally, a low breakdown voltage of about 50V provides high reliability and allows the operation of the device in full daylight without any damage to the detector.

8375-26, Session 7

A Ge-on-Si single-photon avalanche diode operating in Geiger mode at infrared wavelengths

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The Ge APD detectors are fabricated on Si by using a selective chemical-vapor deposition (CVD) epitaxial growth technique. A novel processing procedure was developed for the p+ Ge surface doping by a sequence of pure-Ga and pure-B depositions (PureGaB). Then, PVD Al is used to contact the n-type Si and the anode of p+n Ge diode. Arrays of diodes with different areas, as large as 40x40 µm2, were fabricated. The resulting p+n diodes have exceptionally good I-V characteristics with ideality factor of ~1.1 and low saturation currents. The devices can be fabricated with a range of breakdown voltages from a minimum of 9V to a maximum of 13V. They can be operated both in proportional and in Geiger mode, and exhibit relatively low dark counts as low as 10kHz at 1V excess reverse bias. The dark current at 1V reverse bias are as low as 2pA and 20pA for a 2x2 µm2 and 2x20 µm2 devices, respectively. Higher IR-induced current than that induced by visible light confirms the sensitivity of Ge photodiodes at room temperature. The 25% peak in Id/Iref at an IR-wavelength of 1100nm in Geiger mode is measured for excess bias voltages of 3V and 4V, which Id refers to the photocurrent of the 2x20 µm2 device at different wavelengths, and Iref is the reference photodiode current. The timing response (Jitter) for the APD when exposed to a pulsed laser at 637nm and 1V excess bias is measured as 900ps at full width of half maximum (FWHM).

8375-27, Session 7

Development of small unit cell avalanche photodiodes for UV imaging applications

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High resolution imaging in UV band has a lot of applications in Defense and commercial applications. The shortest wavelength is desired for spatial resolution which allows for small pixels and large formats. UVAPD's have been demonstrated as discrete devices demonstrating gain. The next frontier is to develop UV APD arrays with high gain to demonstrate high resolution imaging.

We will discuss model that can predict sensor performance in the UV band using APD's with various gain and other parameters for a desired UV band of interest. SNR's can be modeled from illuminated targets at various distances with high resolution under standard atmospheres in the UV band and the solar blind region using detector arrays with unity gain and with high gain APD's.

We will present recent data on the GaN based APD's for their gain, detector response, dark current noise and the 1/f noise. We will present various approaches and device designs that are being evaluated for developing APD's in wide band gap semiconductors. The paper will also discuss state of the art in UV APD and the future directions for small unit cell size and gain in the APD's.

8375-28, Session 8

Probabilistic analysis of solid state photomultiplier performance

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New generation of photon detectors - so-called Solid State (Silicon) Photomultipliers (SSPM, SiPM), Negative Feedback APDs (NFAD, NAF), and a few more brand names - is widely recognized to be competitive with PMTs and conventional APDs in various low light level applications. SSPM designs are mostly associated with multi-pixel Geiger mode APD with built-in negative feedback elements. Strong negative feedback applied to Geiger avalanche breakdown enables near ideal single electron multiplication with very high gain and ultra-low excess noise. Multi-pixel architecture provides capability of multi-photon pulse detection with remarkable photon number resolution starting from single photons at room temperature.

On the other hand, the SSPM design concept results in low dynamic range due to limited number of pixels with some dead time and in considerable excess noises of crosstalk and afterpulsing. These specific drawbacks affect signal-to-noise ratio and complicate estimation of the SSPM applicability and competitiveness with other detectors and within the SSPM generation.

This study presents probabilistic analysis of the SSPM and analytical results on probability distributions of the output signals with crosstalk and afterpulsing, accounting of the saturation and non-linearity effects, representation of the key photodetection processes in terms of excess noise factors, and the total detection efficiency in photon number resolution. Correspondences of the analytical models with the experiments as well as comparative analysis of the photon number resolution performance for various SSPM designs are presented and discussed.

Results of the study seem to be useful for the improvements in designing, characterization, and application-specific optimization of the SSPM.

8375-29, Session 8

Photon-number statistics and correlations with silicon photomultipliers

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We present a description of the operation of a multi-pixel detector (SiPM, Hamamatsu) in the presence of non-negligible dark-count and cross-talk effects.

SiPM is a device consisting in an array of identical semiconductor diodes, working at a large reverse bias, over the breakdown voltage, in a Geiger-Muller. Each diode is independent of the others, but they all share a common output, so that the output current is proportional to the number of triggered G-M avalanches. The SiPM construction technology grants them many desirable features, as an enhanced linearity, gain values comparable to standard Photo-Multiplier Tubes, operability in magnetic fields, compactness and limited power consumption, together with undesirable ones, such as dark-count and cross-talk effects.

We elaborate a model of the detector to devise self-consistent calibration strategies to be performed on the very light under investigation. The calibration is then used to evaluate shot-by-shot detected-photon numbers that, of course, also include the effects of dark count and cross talk.

We demonstrate that the analysis allows us to reliably reconstruct the detected-photons statistics of a number of different light states by taking into account the unavoidable modifications introduced by detector characteristics.

By using shot-by-shot measurements we can quantify the photon-number correlation coefficient in bipartite states and use the data to produce conditional states.

Once again the measurements demonstrate that only if the experimental conditions are such that dark-count and cross-talk effects can be neglected, the correlation value and the conditioning operation is what expected from theory.

8375-30, Session 8

InGaAs/InP negative-feedback avalanche diodes (NFADs) and solid state photomultipliers (SSPMs)

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Due to the inherent positive feedback mechanism involved in the impact ionization avalanche process, InGaAs/InP single photon avalanche photodiodes (SPADs) have historically exhibited certain shortcomings such as low counting rate and inability to resolve photon number. To overcome some of the performance limitations of regular SPADs, we have developed negative feedback avalanche diodes (NFADs) which employ a negative feedback mechanism to regulate the avalanche process. The fabrication process of NFADs is flexible and is based on our design platform used to provide industry-leading SPAD performance. The operation of NFAD devices is also very simple, with only a DC bias is required. Various discrete devices and matrices composed of different elements have been designed, fabricated and characterized. For discrete devices, ~10% photon detection efficiency has been realized consistent with acceptable afterpulsing probability, providing a convenient photon-counting solution for certain applications. The negative feedback mechanism significantly improves the uniformity of the output pulse heights and avalanche charge per detection event, resulting in a low “charge excess noise” factor. We demonstrate that when NFAD devices are configured in a matrix format, they have the ability to resolve photon number and work effectively as solid state photomultipliers (SSPMs) in the short wave infrared (SWIR) region. The InGaAs/InP NFAD SSPMs will have the potential to replace photomultiplier tubes and silicon photomultiplier (SiPMs) in applications where single photon sensitivity in the SWIR region is critical.

8375-31, Session 8

Near-photon counting image detector in the mid-infrared

J. S. Dam, C. Pedersen, P. Tidemand-Lichtenberg, Technical Univ. of Denmark (Denmark)

Imaging and detection of light at infrared wavelengths are of great technical and scientific interest due to many important applications, e.g. within thermal imaging and spectroscopy. Low light level detection in the mid-infrared is challenging, and typically requires cryogenic cooling to reach acceptable signal to noise ratios. Even the internal casing of an imaging device needs to be cooled. Although significant advances have been made in the electronics and detector material side of things, fundamental noise issues are considered unavoidable for efficient detection of longer wavelengths. However, we demonstrate a different, fundamentally noise free principle where mid-infrared light, containing image information, is converted to near visible wavelengths with high quantum efficiency. After conversion the radiation can be detected by any near visible light detector, thus effectively extending its working range of e.g. Si-based detectors to the mid-infrared. The method is based on upconversion in a non-linear crystal under mixing with a strong laser field. Since the crystal is transparent there is virtually no dark noise in the system - even when working at room temperature. The dark noise has been measured to be less than 0.1 electrons per pixel per second. The conversion principle is generic, and can be applied over a huge dynamic range from single photons to milliwatts of power. The generic principle presented, even allows for further build-in functionality, e.g. multispectral imaging, allowing for identification of substances with a specific spectral

fingerprint. Furthermore, the mixing process allows for high temporal resolution and high image frame rate.

8375-32, Session 8

Solution-processed, quantun-dot-gated, organic thin-film transistor for single-photon detection

J. Huang, Univ. of Nebraska-Lincoln (United States)

Photomultiplier tubes and avalanche photo-diodes are the most widely used device for weak light detecting. However these devices are generally expensive and need to be cooled for single photon detection. III-V quantum dot, optically gated, field-effect transistor (QDOGFET) has shown capability of photon-number-discriminating but only at low temperature 10 K. due to the low exciton binding energy in inorganic semiconductors. We report a photon-numberresolving capabilities of a quantum-dot, optically gated, field efect transistor that uses quantum dots as optically addressable floating gates by inserting a ZnO QDs layer between the channel layer and dielectric layer. When the active area of the detector is illuminated, photo-generated carriers trapped by quantum dots screen the gate field, causing a persistent change in the channel current that is proportional to the number of confined carriers. The preliminary results demonstrated detection of UV flux of 5 photons/ µm 2 s at room temperature and counting of pulse in the scale of sub-picosecond.

8375-33, Session 9

Readout circuitry for continuous high-rate photon detection with arrays of InP geiger-mode avalanche photodiodes

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An asynchronous readout integrated circuit (ROIC) has been developed for hybridization to a 32x32 array of single-photon counting avalanche photodiodes (APDs). The asynchronous ROIC is capable of simultaneous detection and readout of photon times of arrival, with no array blind time. Each pixel in the array is independently operated by a finite state machine that actively quenches an APD upon a photon detection event, and re-biases the device into Geiger mode after a programmable hold-off time. While an individual APD is in hold-off mode, other elements in the array are biased and available to detect photons. This approach enables high pixel refresh frequency (PRF), making the device suitable for applications including optical communications and frequency-agile ladar. A built-in electronic shutter that de-biases the whole array allows the detector to operate in a gated mode or allows for detection to be temporarily disabled. On-chip data reduction reduces the high bandwidth requirements of simultaneous detection and readout. Additional features include programmable single-pixel disable, region of interest processing, and programmable output data rates. State-based on-chip clock gating reduces overall power draw, with the device consuming approximately 0.5 W at 500 MHz. ROIC operation has been demonstrated with hybridized InP APDs sensitive to 1.06-µm and 1.55-µm wavelength, and fully packaged focal plane arrays (FPAs) have been assembled and characterized.

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8375-34, Session 9

High-speed CMOS time-domain single-photon counting for high-dynamic range and high sensitivity

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Single-photon counters have become attractive imaging tools that are currently used in a number of very low-light level applications such as surveillance and security imaging, quantum computing, and biomedical imaging including bioluminescence and fluorescence lifetime imaging. However, a typical avalanche-based single-photon detector cannot offer the high dynamic range that is needed for many biomedical and surveillance applications. In this presentation, we report on the design of single-photon avalanche photodiodes in 130 nm mainstream digital CMOS technology, with integrated in-pixel peripheral circuitry, such as the preamplifier and time-to-digital converter, achieving sub 100 ps timing resolution. We also show how our single-photon detectors can be used in time-domain for high dynamic range applications. A time-domain single-photon imager (TDSPI) array can use one counter to measure the light power for a fixed integration time or for a fixed count threshold. Novel techniques are used to implement the time-domain single-photon imager in mainstream deep-submicron CMOS technology. Our work shows the design of an imager that can achieve high dynamic range and high sensitivity with frame rates that are 3 to 4 orders of magnitude higher than conventional wide dynamic range imagers. The final pixel design contains a 9-bit dual-port static random access memory, an active quench and reset single-photon avalanche detector, and two cascaded analog counters and threshold detectors. The designed imager offers high dynamic range and high sensitivity, while maintaining high speed operation and is of low cost.

8375-35, Session 9

Linear photon-counting with HgCdTe APDs

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HgCdTe APDs have been shown to exhibit single carrier multiplication (SCM) which gives desirable properties such as low multiplication excess noise (F<1.2) and gain independent response time up to multiplication gains exceeding 1000. Combined with quantum efficiencies (QE) which can approach 100 % in optimized detectors, theses detectors have the highest information conservation ratio QE/F of all amplified detectors, from ultra-violet wavelengths up to the infra-red cut-off of the APDs. Theses properties open new perspectives for photon-counting applications which can be achieved in a linear mode that enables proportional photon-counting, high photon detection efficiency (PDE), low after-pulsing, high count rates and low dark count rates (DCR).

In this communication we present the status of HgCdTe APD technology at CEA/Leti and show first results on photon-counting circuits made of HgCdTe APDs hybridized with specially designed read-out integrated circuits (ROICS). The ROICs are made using compact CMOS electronics to enable integration into large area-small pixel focal plane arrays. The results will be discussed in terms of the impact of the HgCdTe APD gain and response time characteristics on the most common photon-counting figure of merits and which perspectives that can be expected from improved APD and ROIC design.

8375-36, Session 9

Avalanche discrimination and high-speed counting in periodically gated single-photon avalanche diodes

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Reducing the afterpulse probability in a single-photon avalanche diode (SPAD) allows reliable single-photon counting at higher frequencies. Recently a handful of periodic-gating techniques have been developed that reduce the afterpulse probability in SPAD detection systems, in part, by reducing the total amount of charge that flows during an avalanche, and these techniques have been used to demonstrate single-photon count rates above 100 MHz. The performance of these approaches relies crucially on the ability to discriminate avalanche signals from both the residual gating signal and noise in the overall detection system, and is fundamentally limited by Johnson noise at the SPAD output. We discuss various techniques for avalanche discrimination in periodically-gated SPAD systems and present an approach that supports avalanche discrimination thresholds below 30 fC, approaching the Johnson noise limit. We demonstrate single-photon counting above 100-MHz with low afterpulse probability and discuss trade-offs between detection efficiency, count rate, and noise in this regime. Finally, we present an analysis of the avalanche waveform and show that in our system it is the multiplication noise in the SPAD itself that limits the detection efficiency.

8375-37, Session 9

Improved sinusoidal gating operation of InGaAs/InP single-photon avalanche diodes

Z. Lu, Univ. of Virginia (United States)

We report sinusoidally gated InGaAs/InP single photon avalanche diodes (SPAD) operated at wavelength of 1310 nm with high photon detection efficiency (PDE) and low dark count rate (DCR). At a gating frequency of 80 MHz and temperature of 240 K the DCR and PDE were 15.5 kHz and 55%, respectively. We find that the slope of DCR versus PDE increases with at higher laser repetition rate. There are two mechanisms that contribute to this trend. The first is due to the lower afterpulse probability associated with a lower laser repetition rate. The other is due to the RC time effect, which will be illustrated by an equivalent circuit that includes a model of the SPAD. We also show that relative to gated passive quenching with active reset (PQAR) for fixed PDE, sinusoidal gating produces lower afterpulsing rates at the same hold off time. This will be explained in terms of the integrated pulse shape and the resultant charge flow. By adjusting the DC bias and AC voltage swing, an optimized operating condition to achieve minimum afterpulsing with the same PDE and DCR can be achieved. This type of analysis could provide guidelines for other gating schemes. We also show that the afterpulse probability, Pa, is related to the hold off time through the power law, Pa T-α. The parameter, α, is a measure of the detrapping time in the multiplication region. We will present comparisons of experimental α values for different SPADs.

8375-38, Poster Session

Measuring isomeric transitions in holmium-166 using a time-gated pmt

S. L. Henriquez, M. S. Litz, J. J. Carroll, U.S. Army Research Lab. (United States)

If our understanding of the long-lived nuclear isomer holmium-166m is correct, irradiation with 2 MeV bremsstrahlung can initiate a decay of holmium-166m into holmium's ground state and emission of a 137 keV photon with a 185 μs half life. In our experiment an enriched 166mHo sample is irradiated by 5 μs long and 2 MeV bremsstrahlung pulses from a linear accelerator, after which the photons must be counted for many half lives. The project is to design a system that can count the individual photons within less than 50 μs to 100 μs after radiation scattered from the measurement setup has affected the scintillator-photomultiplier combination that counts the gamma rays. As in LIDAR and laser-induced fluorescence, the photomultiplier must be gated to maximize its recovery time, while the scintillator's decay time must be short enough to enable photon counting to resume on time. The best choice for the scintillator is LaCl3 due to its 16 ns decay time, high atomic number, and high efficiency. To date, we have implemented two of the gating circuits suggested in the literature, and compared their performance. Neither of the methods has been satisfactory.

8375-39, Poster Session

Picosecond-resolved FRET on non-amplified DNA for identifying individuals genetically susceptible to type 1 diabetes

M. Bondani, L. Nardo, G. Tosi, R. Accolla, A. Andreoni, Univ. degli Studi dell'Insubria (Italy)

We identify allelic sequences of the DQB1 gene of the human leukocyte antigen (HLA) system conferring susceptibility to develop type 1 diabetes in DNA samples with no need of polymerase chain reaction (PCR) amplification.

Our method relies on the time-resolved analysis of a Förster energy-transfer mechanism that occurs in an oligonucleotide probe specific for the base sequence of the allelic variant, DQB1 0201, mainly responsible for susceptibility. The probe carries donor and acceptor at opposite ends. As quenching depends on donor-acceptor distance, we distinguish among probe conformations after hybridization with DNAs either containing or not the DQB1 0201 sequence. By time-correlated single-photon counting, we measure, with 30-ps resolution, the donor fluorescence decay time, tD, and discriminate the DNA bearing the "susceptible" allele, DQB1 0201, from the DNAs bearing any other sequence in the same region of the DQB1 gene. The greatest tD value (2723 ps), revealing maximum donor-acceptor distance, corresponds to the perfect matching of the probe with the complementary DQB1-0201 sequence. The next highest tD value (2603 ps) is found for the 0302 sequence, which is also responsible for susceptibility. Other hybrids yield values between 2466 and 2512 ps.

As this typing method is relatively simple and cost effective, it could be adopted for routine typing not only of HLA, but also of specific "pathologic" sequences, for example of mutated oncogenes, in order to identify the specific mutation in tumor tissues and most importantly the extent of mutated genes in pre-neoplastic lesions.

8376-01, Session 1

Large-area and label-free plasmonic microarrays

H. Altug, M. A. Huang, T. Chang, A. A. Yanik, H. Tsai, P. Shi, S. Aksu, M. F. Yanik, Boston Univ. (United States)

Microarray technologies, enabling high-throughput and large area studies on biomolecules, pharmaceutical compounds and protein interactions, can dramatically facilitate early identification of complex diseases as well as discovery of most effective drugs for their treatment. State-of-the-art microarray technologies rely on fluorescence based detection. However, protein functions have to be deciphered without using labeling techniques since label interfere with molecular binding interactions and can lead to unreliable conclusions. Furthermore, photo-bleaching and quenching of labels also cause significant limitations for quantitative analysis.

In this talk, we will present our work demonstrating for the first time a plasmonic-based high-throughput and label-free microarray technology that can reliability and rapidly identify biomolecular interactions in a large scale. We will present a fabrication approach enabling plasmonic microarray technology with over one million sensors on a single microscope slide. We will also introduced a dual-color filter imaging method to increase the accuracy, reliability, and signal-to-noise ratio of the sensors for working in a highly multiplexed format with reduced image acquisition time. Unlike current optical nanosensors, our technology based on dual-color filter imaging through plasmonic nanoholes, enables high-speed and accurate sensing with high signal-to-noise ratio. Compare to the conventional fluorescence microarrays, our platform reliably allows direct quantitative analysis of bio-molecular interactions, and eliminates many significant problems such as steric interference, photo-bleaching and high cost of labeling. Furthermore, since our system is highly compatible with the current commercial microarray scanners, it can enable the next generation high-throughput screening technologies and significantly impact biomedical and pharmaceutical field.

8376-02, Session 1

Thermally modulated nanotrampoline material as smart skin for gas molecular mass detection

H. Xia, GE Global Research (United States)

Conventional gas composition analysis is based either on laser spectroscopy, laser and photo-acoustic absorption at specific wavelengths, or on gas chromatography by separating the components of a gas mixture primarily based on boiling point (or vapor pressure) differences. This talk will present a new gas molecular mass detection method based on thermally modulated nano-trampoline material as smart skin for gas molecular detection by fiber Bragg grating-based gas sensors. Such a nanomaterial and fiber Bragg grating integrated sensing device can be operated either at high-energy level (highly thermal strained status) or at low-energy level (low thermal strained status). Thermal energy absorption of gas molecular from high-thermal-energy status could trig the sensing device transition to low-thermal-energy status. Experiment has shown that thermal energy loss due to gas molecular heat absorption is dependence upon the gas molecular mass, and can be detected by fiber Bragg resonant wavelength shift with a linear function from 17 kg/kmol to 32 kg/kmol and a sensitivity of 0.025 kg/kmol for a 5 micron-thick nano-trampoline structure and fiber Bragg grating integrated gas sensing device. The laboratory and field validation data have further demonstrated its fast response characteristics and reliability to be online gas analysis instrument for measuring effective gas molecular mass from single-component gas, binary-component gas mixture, and multi-gas mixture. The potential industrial applications for petrochemical process in ethylene production, fuel quality for gas turbine, and gas purity for hydrogen-cooled generator will be discussed.

8376-03, Session 1

High-throughput nanostructured SERS substrates by self assembly

O. Rabin, R. M. Briber, S. Y. Lee, W. Lee, Univ. of Maryland, College Park (United States)

The fabrication of surface-enhanced Raman spectroscopy (SERS) substrates that are optimized for use with specific laser wavelength - analyte combinations is addressed. In order to achieve large signal enhancement, temporal stability, and reproducibility over large substrate areas at low cost, only self-assembly and templating processes are employed. The fabrication involves (1) assembly of block copolymer films with nanoscale hexagonally-ordered domains, (2) the chemical stabilization of the structure, (3) deposition of gold nanoparticles of the polymer through electrostatic interactions, and (4) adjustment of the nanoparticle diameter by electroless deposition. The resulting substrates consist of arrays of gold nanospheres with controlled diameter and spacing, properties that dictate the optical response of the structure. We observe tunability of the extended surface plasmon resonance in the range of 520-1000 nm. We demonstrate that the enhancement factor is maximized when the surface plasmon resonance is red-shifted with respect to the SERS instrument laser line. Despite relying on self-organization, we obtain site-to-site enhancement factor variations smaller than 10%. The mild conditions and robustness of the fabrication allows to include these SERS substrates in microphotonic devices.

8376-04, Session 1

Plasmonic enhancement of a whispering gallery-mode biosensor for single nanoparticle detection in aqueous solution

S. I. Shopova, R. Rajmangal, Polytechnic Institute of New York Univ. (United States); S. Holler, Fordham Univ. (United States); S. Arnold, Polytechnic Institute of New York Univ. (United States)

The need for early detection of pathogens and antibodies, that are generated as a biological response, drives the invention of ultra-sensitive label-free biosensors that can detect individual bio-nanoparticles in aqueous solution. We demonstrate a mechanism that involves creating local plasmonic “hot spots” near the sensing equator within the WGM’s evanescent field. A controlled deposition of plasmonic particles was accomplished by guiding a plasmonic nanoparticle to the microsphere’s equator using carousel forces. A dielectric nanoparticle is easily caught at one of these spots due to enhanced gradient forces. Since the hot spots are part of the local field of the plasmonically modified microresonator, the frequency of the resonator undergoes an enhanced shift as a particle binds to one of these spots in comparison with binding to the bare resonator. Based on the reactive sensing principle, the enhancement RE is produced by the relative increase in polarization energy of an analyte particle at a hot spot in comparison to that in the absence of the plasmonic particle. Consequently RE can be estimated from the ratio of the intensity at the hot spot to the intensity in the same region in absence of the metallic particle. The experimentally observed frequency shifts are enhanced by 4x, consistent with this reactive model. Based on this mechanism we show that enhancements of several orders of magnitude are achievable for particles of size comparable with the extend of the local field of the “hot spot”. This puts individual protein molecules (e.g. BSA) within the detection limit of such plasmonically enhanced WGM sensor.

8376-05, Session 2

Surface-enhanced nanoplasmonic sensing and imaging of biomolecular processes

D. Kim, Yonsei Univ. (Korea, Republic of) and Yonsei Institute of Medical Instruments Technology (Korea, Republic of)

There has been an exponential growth of interests in nanoplasmonics for enhanced optical characteristics useful in various biomedical engineering applications. While traditional thin film-based plasmon detection allows molecular imaging and sensing by localizing evanescent fields axially, nanoplasmonics further enables localization of near-fields in the lateral plane and empowers researchers with novel approaches that were previously deemed unrealizable.

Surface-enhanced nanoplasmonic substrates can create locally amplified electromagnetic near-field or hot spots as a result of evanescent field localization. The production and maintenance of hot spots have been explored in many studies because of the potential for enhanced detection sensitivity and improved resolving power in imaging applications.

In this direction, three key aspects need to be considered, i.e., surface plasmon enhanced localization and amplification of near-fields, management of target distribution, and novel detection strategies. In particular, this presentation will describe recent approaches for efficient excitation of localized surface plasmon using nanostructures aimed at diverse target interactions including DNA hybridization, antigen-antibody binding, and intra/extracellular protein dynamics. Also discussed are the efforts to manage and control target molecular distribution. The colocalization of target molecules with localized near-fields may be critical to the enhancement of optical signatures by making an optimal use of field localization. In addition, novel detection schemes such as phase imaging, which may be combined with nanoplasmonics for enhanced sensing and imaging, will be presented.

8376-06, Session 2

Sensitivity enhancement and detection-limit improvement in whispering gallery-mode-based biosensing

Y. Xiao, B. Li, Peking Univ. (China)

Recently, whispering-gallery-mode (WGM) optical microresonators, possessing ultrahigh Q factors and small mode volumes, have attracted increasing interests ranging from fundamental physics studies to device applications. In sensing applications, the mode shift or splitting induced by biomolecules or nanoparticles are typically regarded as the sensing signals. Here we propose several schemes to improve the performance of WGM based biosensing, including sensitivity enhancement and the detection limit improvement.

For mode shift detection scheme, we propose a new kind of plasmonic WGM, which is highly localized in the exterior of the metal-coated toroidal microresonator. With more than 90% energy locating in the exterior, this exterior-WGM-based sensor has a dramatically high sensitivity up to 500 nm/RIU at 680 nm wavelength band, which is one order of magnitude higher than conventional WGM-based sensors.

For mode splitting scheme, a multi-particle induced splitting mechanism is proposed, which can extend the detection range (lower the detection limit), compared with single-particle case. In addition, the detection limit can be further lowered by performing data post-processing, i.e., statistical analyses of multi-measurements. Particle sizing detection limit as low as 5 nm is achieved, which indicates that single protein molecule detection is reachable with this method. Utilizing the polystyrene (PS) nanoparticles to simulate the biomolecules, we experimentally present the detection of PS nanoparticles in aqueous environment with the split WGMs. With Q factor as high as 0.82×108 in aqueous environment, single nanoparticles detection has been achieved. The dynamic evolution of the mode splitting is also explained.

8376-07, Session 2

Multi-axis all dielectric electric field sensors

S. Chadderdon, D. T. Perry, J. Van Wagoner, Brigham Young Univ. (United States); W. C. Wang, R. A. Forber, IPITEK, Inc. (United States); R. Selfridge, S. Schultz, Brigham Young Univ. (United States)

This paper presents innovations that reduce the dimensions and interrogation complexity of a previously developed multi-axis electric field sensor. These sensors which are based on slab coupled optical sensor (SCOS) technology are used to measure electric fields created by high powered microwave and electromagnetic pulse weapons. A SCOS device functions as an electric field sensor through use of resonant mode coupling between an electro-optic slab waveguide and optical fiber platform. The resonant mode coupling of a SCOS device occurs at specific wavelengths whose spectral locations are determined in part by the effective refractive index of the modes in the slab. An electric field changes the refractive index of the slab causing a shift in the spectral position of the resonant modes. Electric field sensing is achieved by tuning a laser to an edge of a resonant mode and measuring power fluctuations. It is sensitive to electric fields that are parallel to the optic axis of the electro-optic slab. Electric fields are measured in multi-axes by mounting SCOS devices, which have slabs with optic-axes perpendicular to the fiber (z-cut), orthogonal to each other. In order to reduce dimensions of the sensor, the third-axis or longitudinal electric field is measured by having a slab with the optic-axis parallel to the fiber (x-cut). By rotating a z-cut slab waveguide on the optical fiber the spectral position of the resonance modes are tuned to match those of an x-cut slab. This enables the multi-axes sensor to be interrogated with a single laser source.

8376-08, Session 3

Porous materials for optical detection of chemicals, biological molecules, and high-energy radiation

S. M. Weiss, Vanderbilt Univ. (United States)

Porous materials offer several advantages for chemical and biomolecular sensing applications. In particular, nanoscale porous materials possess a very large reactive surface area to facilitate the capture of small molecules, and they have the capability to selectively filter out contaminant molecules by size. This presentation will discuss the fabrication, functionalization, and application of porous silicon waveguides and diffraction gratings, porous gold SERS templates, and silicon photonic crystal microcavities for the detection of small chemical and biological molecules. Issues of efficient molecule infiltration and capture inside porous materials, binding kinetics in nanoscale pores, the influence of pore size on small molecule detection sensitivity, and the new nanoscale patterning technique of Direct Imprinting of Porous Substrates (DIPS) will be addressed. Additionally, a novel application of porous silicon for detection of x-ray radiation will be introduced.

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8376-09, Session 3

Nanostructured photonic biosensors for medical diagnosis and analyzing cellular signals

E. Tamiya, Osaka Univ. (Japan)

Nanostructured metals have been studied for the localized surface plasmon resonance (LSPR) and electrochemical biosensors. Photonic plasmon spectra are caused by the refractive index variations that result from the binding of molecules to the metal nanostructures. There are optically detectable parameters in biophotonics and biosensor devices. We have studied three types of nanostructures, gold-capped nanostructure connecting with the core of silica nanoparticle capped by deposited gold film, gold-deposited porous anodic alumina layer chip and gold nanoparticles onto silicon oxide /silicon interferrometric multilayer as our original works. The bio-sensing of these nanostructures have been examined by monitoring the biomolecular interactions in various flexible formats. Antibody-antigen and DNA hybridization reactions were performed to detect various biomarkers, with the detection limit of picogram levels. The multi array format was constructed by a core-shell structured nanoparticle layer, which provided 300 spots on the sensing surface. A microfluidic biochip based on PDMS was useful for real-time analysis, rapid detection. DNA amplification process (PCR) and monoclonal antibody production from hybridoma cell library can be monitored. Electrochemistry measurements connecting to core-shell structure nanoparticle were successfully exploited in a simultaneous detectable scheme. The binding of melittin to lipid membrane was measured using localized surface plasmon resonance, and the permeability of the lipid membrane was then assessed electrochemically as a function of melittin with the purpose of seeking a novel, sensitive detection system for peptide toxins. Surface Enhanced Raman Scattering (SERS) was also discussed with gold and silver nanoparticles interacting with bio-molecules. Gold nanoparticles were successfully delivered into single cells. Spatiotemporal measurements of SERS fingerprints suggested the dynamic molecular interactions and transformations taking place at different locations with time in cardiomyocytes.

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8376-10, Session 3

In vivo experiments of laser thermotherapy on liver tissue with FBG temperature distribution sensor

N. Chen, S. Chen, H. Zhu, S. Liu, Z. Chen, F. Pang, T. Wang, Shanghai Univ. (China)

In this paper, we report an in vivo experimental study of liver tissue during Laser Induced Interstitial Thermotherapy (LITT). Single FBG was used in the experiments to measure the distributed temperature profile of the bio tissue in real time. LITT has been used in surgery as a minimally invasive method for treating different types of tumors in liver, brain, head and neck, etc. Ideally, the goal of LITT is to kill pathological tissue thoroughly and minimize its damage to surrounding healthy tissue, especially vital organs. The extent of treated tissue damage in the therapy is mainly dependent on the irradiation time and the laser power density at the tissue surface. Therefore, monitoring the dynamic change of the exact temperature distribution of the tissue is a key point for the safety of this treatment. In our experiments, FBG was embedded in the laser irradiated bio tissues and used as fully distributed temperature sensor. During the therapy, its reflection spectra were recorded and transmitted to PC in real time. The temperature profile along the FBG axial was reconstructed from its reflection spectrum by the spectra inversion program running on the PC. We studied the dependence of the temperature distribution and laser output power experimentally and compared the results of in vivo and in vitro under similar laser irradiating conditions. Experimental results demonstrate the effectiveness of this method. Due to influence of body temperature, the in vivo measured temperature is higher than the in vitro one with an almost constant temperature difference value, but the slope and trend of the measured temperature curves in vivo and in vitro are almost identical.

8376-11, Session 3

Highly sensitive detection of glucose concentration with opto-fluidics ring resonator

Y. Luo, Jinan Univ. (China); X. Fan, Univ. of Michigan (United States)

Precise measurement of blood glucose has become a worldwide focused issue. The optical techniques, including near infrared spectroscopy, mid-infrared spectroscopy, Raman spectroscopy, photo-acoustic spectroscopy, optical coherence tomography, have emerged as promising non-invasive methods. However, these methods suffer from a common problem, that is, low sensitivity and strong background noise. Here, we describe a minimally-invasive and highly sensitive method to detect glucose concentration. The optofluidics ring resonator (OFRR) is adopted to measure the change in refractive index of interstitial fluid, which is induced by the variation of glucose concentration. The detection limit down to micro-molars per liter is possible, exceeding the clinical requirements.

The OFRR consists of a thin-walled fused-silica capillary and an optical fiber taper. A 1550 nm tunable laser is coupled into the capillary and excites the whisper gallery modes. A layer of protein molecules are immobilized on the inner surface of the capillary and capture glucose, when the interstitial fluid flows through the capillary. Using the OFRR as a glucose sensor offers a few distinct advantages. First, the OFRR has a very high Q factor, leading to an excellent detection limit. Second, the excellent microfluidics of a capillary results in rapid response time and extremely low sample volume. Third, the capillary is highly compatible and can be easily integrated with interstitial fluid extracting system, which is critical to minimally invasive painful detection.

8376-12, Session 4

Manipulation and sensing with surface plasmonic lens-based fiber optic tweezers

M. Yu, Univ. of Maryland, College Park (United States); Y. Liu, National Institute of Standards and Technology (United States)

Optical tweezers have been important tools in biology and physics for manipulation of micro/nano sized particles. They can be used as both sensors and actuators to measure displacements as small as a nanometer and probe forces as small as a pico-newton. Optical traps built with optical fibers provide an appealing solution for cost and size reduction with enhanced flexibility, and can be potentially integrated into a lab-on-a-chip system. However, current fiber optical tweezers have limitations such as low trapping efficiency, limited functionality, and imprecise dynamical trapping position control, which prevent them from being used in a wide range of applications. In this paper, we first review our recent progress on development of a dexterous dual fiber tweezers system with greatly enhanced flexibility, functionality, and efficiency. This system will enable multiple traps which can be used to perform multiple functions including particle grouping, separation, and stacking. Furthermore, we will discuss our recent effort on developing a surface plasmonic (SP) lens based fiber optic tweezers. The gold SP lens on a fiber endface enables a focus that is smaller than the diffraction limit, which can significantly enhance the trapping efficiency. It is demonstrated that with the SP lensed fiber, bacteria and beads with sizes

of several hundred nanometers can be successfully trapped. Through bridging microscale optical fibers and nanophotonic structures, this work can potentially open doors to the applications of fiber optic tweezers in nanometer regime.

8376-13, Session 4

Optical fiber sensor interrogation improved by active fiber loop

T. Wei, J. Huang, X. Lan, Missouri Univ. of Science and Technology (United States); Q. Han, Missouri Univ. of Science and Technology (United States) and Tianjing Univ. (China); H. Xiao, Missouri Univ. of Science and Technology (United States)

This paper summarizes the recent progress of improving optical fiber sensor interrogation technique by introducing acitve fiber loop into demodulation system in our lab. Evanescent field based optical fiber sensors are highly sensitive to ambient refractive index change. With functional material coating, they can be developed as chemical trace sensors. However, the broadband resonant peak or notch is a challenge to signal processing. On the other hand, optical fiber laser with a bandpass filter can lase at single frequency with narrow linewidth. By developing existent optical fiber sensors into bandpass filter form, the narrow linewidth laser can be directly used to interrogate the sensor signal. Various types of sensors including multimode interferometer chemical vapor sensor, micro fabircated Mach-Zehnder interferometer and etc are implemented in the active fiber loop interrogation system. The experiments shows an improved signal to noise ratio by active fiber loop.

8376-14, Session 4

Interrogation of in-series double cladding fiber sensor for simultaneous refractive index and temperature measurement

B. Qi, F. Pang, T. Wang, N. Chen, S. Huang, Z. Chen, Shanghai Univ. (China)

Fiber-optic dual parameters sensors have many important applications in chemical sensor and biosensor. Some technologies have been proposed and investigated, including fiber Bragg gratings, long period gratings, Fabry-Perot cavities and so on. These methods generally need complex post-processing techniques. Recently, a special double cladding fiber (DCF) has been proposed and investigated for sensor applications. The DCF can be easily spliced with standard single mode fibers (SMF) to construct a sensor head of “SMF-DCF-SMF”. Through the evanescent wave coupling effect, cladding modes can be resonantly excited in the DCF section, and thus a band-rejected filtering transmission spectrum can be obtained. By monitoring the change of the transmission spectrum, the sensor has been applied to measure temperature, refractive index (RI) and bend. Besides, a dual-parameter sensor by cascading two different DCFs was also studied, which was interrogated by an optical spectrum analyzer (OSA). In this paper, a novel interrogation scheme for the in-series DCFs sensor is proposed and demonstrated, which can be used for simultaneous refractive index (RI) and temperature measurement. It utilizes two commercial distributed feedback lasers to match the two cascade DCF sensors which have two band-rejected filtering spectra at different wavelengths. The two lasers were intensity modulated by different frequencies and demodulated by a lock-in amplifier. Experimental results indicated that a resolution of $\pm 2\times 10^{-5}$ in RI and ±1.2 in temperature were achieved. Based on the simple and low cost interrogation scheme, the dual parameters sensor system will find potential applications in chemical sensors and biosensors.

8376-15, Session 4

High-sensitivity electro-optic CO_2 gas sensing based on absorption spectroscopy

S. N. Zhang, D. Y. Wang, J. Gong, Virginia Polytechnic Institute and State Univ. (United States); D. Fan, Wuhan Univ. of Technology (China); B. Dong, M. Fraser, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

We reported a high-sensitivity CO2 gas sensing system based on wavelength scanning absorption spectroscopy. A distributed feedback (DFB) laser was used as the light source in the system, whose wavelength was thermally tuned, by a thermoelectric cooler (TEC), to scan around one CO2 absorption line near 1572nm. Scanning of the absorption line spectrum is performed over a glass CO2 gas cell, 16.5cm long with collimated optical fiber connectors. Different concentrations of CO2 were prepared by a high-precision gas flow control meter and sealed within the gas cell. A self-designed detection and amplification circuit was employed for absorption spectrum detection. The circuit implements background-cancellation with a two tier amplification scheme. By cancelling the high background signal, we can improve the CO2 sensitivity by about two orders of magnitude compared with commonly used direct detection methods with high background signals. Reducing the high DC signal permits isolated amplification of the absorption line spectrum. Absorption spectra of different CO2 concentrations were measured, and the results demonstrated sensing capability of 100% to <0.1% concentration of CO2. This sensing system is expected to be used in conjunction with a wireless CO2 sensor network for large area CO2 monitoring. Given the very low power consumption of the DFB laser and the detection circuit, this sensing system offers a solution for affordable long term CO2 monitoring for reliable storage in carbon sequestration.

8376-26, Poster Session

Transformation optics designed general optical Luneburg lens with flattened shapes

K. Ohlinger, Y. Lin, H. Zhang, Univ. of North Texas (United States)

Engineered optical solutions to imaging problems have applications in increasing the efficiency and assembly ease of small scale devices. Of recent interest is the well studied, so called, Luneburg lens, which has the advantage over a traditional lens of being aberration free. Advances in nano/micro fabrication have attracted increased interest in this lens design because techniques are approaching the capabilities necessary to realize it in the optical regime. The transition to fabrication realities imposes many constraints that have been addressed well by others with regards to constituent material properties. Further design modification is required in order to specifically address fabrication procedures and final application assembly. Lithography and many other fabrication processes necessitate construction on a substrate, most commonly flat. This presents a morphological constraint on an inherently spherical design (e.g. the conventional Luneburg lens). Thus we propose to modify the general Luneburg lens by the methods of transformation optics to reflect the flat substrate by truncating the spherical design along the axial direction. We will present the effect of various truncation ratios of the sphere on the material parameters to ensure that the modification lies within the available material properties of various polymer photoresists. Of the well studied Luneburg Lens designs we choose that of a shelled two-external foci arrangement. The effect of the truncation on the shell thickness and the placement of a foci inside the substrate are also investigated. In this way the Luneburg lens is furthered in its practicable design.

8376-16, Session 5

Photonic crystal electro-optic devices in engineered thin film lithium viobate substrates

V. E. Stenger, SRICO Inc. (United States)

We report on photonic crystal electro-optic modulator devices formed in engineered thin film lithium niobate (TFLN) substrates. Photonic crystal devices previously formed in bulk diffused lithium niobate waveguides have been limited in performance by the depth and aspect ratio of the photonic crystal features. We have overcome this limitation by implementing enhanced etching processes in combination with bulk thin film layer transfer techniques. Photonic crystal lattices have been formed that consist of triangular or square arrays of holes. Various device configurations have been explored, including Fabry Perot resonators with integrated photonic crystal mirrors and coupled resonator structures. Both theoretical and experimental efforts have shown that device optical performance hinges on the fidelity and sidewall profiles of the etched photonic crystal lattice features. With this technology, very compact photonic crystal modulators on order of 10 um x 10 um in size have been fabricated that have comparable performance to a conventional 2 cm long bulk substrate device. Advancements to the experimental designs are in progress and preliminary modeling results are presented. It is envisioned that the photonic crystal device technology will have broad application as a compact and minimally invasive probe for sensing any of a multitude of physical parameters, including electrical, radiation, thermal and chemical.

8376-17, Session 5

3D soft waveguides: the ability of pegda gel to guide light

R. Perez-Castillejos, O. Ordeig, New Jersey Institute of Technology (United States)

Planar-waveguides sensors monitor chemical species located at the waveguide surface on the basis of the interaction of the evanescent wave with the recognition element. In contrast to evanescent field sensors, recent studies shown that in 3D-waveguide sensors the light interaction with the recognition element (embedded in the waveguide structure) is of the whole field enabling a reduction of the sensor dimensions and/or a decrease of its limit of detection. The need remains for 3D light-guiding materials that are compatible with biomolecules and living cells.

Hydrogels such as poly(ethylene glycol) diacrylate (PEGDA) are 3D polymeric matrices that retain large volumes of water. PEGDA is a relevant material in tissue engineering due to its biocompatibility and its easy structurization by UV photopolymerization.

Here we introduce the ability of PEGDA hydrogels to guide light and therefore to act as soft (gel) waveguides. PEGDA was structured as a strip along the axis of a glass-and-polydimethylsiloxane (PDMS) microfluidic channel.

The ability of the PEGDA waveguide to confine light was studied by comparing the attenuation of white light traveling an equivalent distance across (i) air, (ii) phosphate buffered saline, and (iii) a strip of PEGDA. Our results show that the attenuation in PEGDA is about half of that in PBS, despite the higher scattering losses associated with PEGDA (due to its porous structure) than with liquid or air.

PEGDA waveguides will make possible to monitor in real time the activity of the biological molecules and cells encapsulated in its network.

8376-18, Session 5

Cathodoluminescence of conducting gratings and implications for electron-beam investigations of nano-photonic devices

J. Nath, C. Schwarz, R. E. Peale, L. Chernyak, Univ. of Central Florida (United States); W. R. Buchwald, Solid State Scientific Corp. (United States)

Nanophotonics is being investigated for a wide range of applications and is based on the excitation, detection, and manipulation of surface plasmon polaritons (SPPs). Excitation of SPPs by electron beams hitting the surface in principle allows the study of SPP effects at the same spatial resolution as the focused e-beam, i.e. ~10 nm. SPPs may be out-coupled as light using suitable structures and spectrally resolved by Cathodo-luminescence spectroscopy. This paper reports such studies on conducting and semi-conducting lamellar nano- and micro-size gratings of varying periods and grating-amplitudes. The overall emission spectrum consists of a 400 nm wide band centered at ~600 nm which depends little on the grating-period, grating-amplitude, material, or e-beam energy, but blue-shifts with e-beam current For the larger amplitude-gratings, modulation of the emission spectrum appears, which can be interpreted as interference from surface emission from grating bars and grooves. The emission band appears only in the presence of a grating, but the spectra appear unchanged as a function of distance of the e-beam spot from the grating edge up to several mm, showing little signature of SPPs. The interference effects suggest that radiation is emitted simultaneously from areas of several tens of micron diameter even for an e-beam spot of just ~10 nm, which might be explained by hot electron current that excites electron-hole pair emission over broad areas. Though the origin of the emission remains unclear, previously suggested mechanisms such as collapsing-dipole, transition radiation, surface contamination, and inverse photo-electron effect can be rejected on theoretical grounds.

8376-19, Session 5

Characterizations of light coupling between side polished fiber and optofluidic ring resonator

Y. Luo, Jinan Univ. (China); X. Fan, Univ. of Michigan (United States)

The optical ring resonator in the form of microspheres and microcylinders has attracted much research focus for potential chemical/biomedical sensing applications. In those ring resonator systems, an optical fiber taper is usually used to guide and couple the resonant light into the whispering gallery mode of the ring resonator. However, the fiber taper is fragile, easy to degrade, and difficult to reproduce, which poses a challenge to move the ring resonator out of a lab for field applications. Here we present studies of using a side polished fiber (SPF) in an attempt to replace the fiber taper. The SPF is fabricated by the wheel-polishing method using a single mode fiber (SMF). They are robust, easy to handle, and can be mass produced. The parameters of the SPF, such as length of polished portion, polished depth, and roughness, can be well controlled during the fabrication. Here we theoretically analyze the effects of above parameters on the coupling. Additionally, using the hollow capillary ring resonator as a model system, we experimentally demonstrate the coupling between the ring resonator and the SPF.

8376-20, Session 5

Fiber Bragg gratings fabricated using a high-repetition rate femtosecond laser

A. Kaur, T. Wei, Q. Han, H. Xiao, H. Tsai, S. E. Watkins, Missouri Univ. of Science and Technology (United States)

Fabrication of optical fiber Bragg gratings (FBG) using a high repetition rate Titanium: sapphire femtosecond laser, and its applications are described. The FBGs were written on a standard single mode fiber using femto-second (fs) laser. Both point-by-point, and line-by-line techniques were explored and results obtained from the two have been discussed. The effects of the fiber cylindrical geometry on the fabrication outcomes were studied using geometric optics. Effects of various related parameters (alignment, power, repletion rate, liquid immersion, etc.) on the grating performance were discussed. An optical fiber ring laser based method was investigated to interrogate the gratings. The FBGs were tested for measurements of temperature and strain.

8376-21, Session 6

Exact analytical solutions to one-dimensional photonic detector with variable mass

J. M. Lopez, Univ. EAFIT (Colombia)

An analysis of 1-dimensional quantum device is presented by comparing between two possible mathematical methods. The first is a continuous scheme where both the mass and the potential vary along the Z-axis, while the second one presents segmentation in three main sections where the mass remains constant along each phase. These analysis where made with the help of a Computer Algebra Software (CAS) due to its extensive mathematical development. A discussion about both schemes and its possible applications to photonic devices are presented.

8376-22, Session 6

Novel approach to improve reliable color recognition in a-Si:H photodiodes

K. Watty, A. Bablich, K. Seibel, C. Merfort, M. Boehm, Univ. Siegen (Germany)

Optical detection is an often used technique for recognition of potentially dangerous materials. Hydrogenated amorphous silicon (a-Si:H) technology provides an inexpensive alternative material compared to crystalline silicon for being used in photonic devices operating in the visible spectrum. Further materials' key benefits are the high light absorption, the voltage-tunable spectral sensitivity and the high space efficiency. Present research efforts concentrate on the determination of the color information in a-Si:H photodiodes. This work presents an approach to improve color recognition of a-Si:H photodiodes by modifying the layer sequence.

The maximum of the spectral response (SR) of a single i-layer a-Si:H photodiode can be shifted by varying its bias voltage. In this case, the shift is not more than some nanometers. Precise color recognition requires different SR maxima (e.g. RGB-model). One possibility to accomplish a separation of the SR is to engineer the bandgap; another idea, which is presented here, is based on a layer sequence modification. Normally, the SR at higher reverse bias voltages, with the maximum at longer wavelengths, encloses that at lower voltages. Splitting the SR leads to an improvement of color recognition and is achieved by depositing an additional interior anode. The SR maximum shift amounts to 100nm, from 540nm by contacting the interior anode, to 640nm at the top anode. Furthermore, the curves are clearly split. The presented approach should lead to a tunable multi-spectral photodiode for high quality color recognition. Such a diode can be used in photonic devices, e.g. for safety and security applications.

8376-23, Session 6

III-nitride/SiC avalanche photodetectors for enabling compact biological agent identification and detection

A. V. Sampath, U.S. Army Research Lab. (United States); Q. Zhou, Univ. of Virginia (United States); R. W. Enck, C. Gallinat, U.S. Army Research Lab. (United States); D. McIntosh, Univ. of Virginia (United States); H. Shen, U.S. Army Research Lab. (United States); J. C. Campbell, Univ. of Virginia (United States); M. Wraback, U.S. Army Research Lab. (United States)

The development of low cost and compact biological agent identification and detection systems, which can be employed in place-and-forget applications or on unmanned vehicles, is constrained by the photodetector currently available. The commonly used photomultiplier tube has significant disadvantages that include high cost, fragility, high voltage operation and poor quantum efficiency in the deep ultraviolet (240-260nm) necessary for methods such as fluorescence-free Raman spectroscopy. Silicon APDs can address some of these constraints but are still inadequate for these applications due to high dark current for linear mode operation and poor ultraviolet quantum efficiency. Emerging technologies include APDs based on SiC or GaN, but the former has poor DUV sensitivity and no response at visible wavelengths while the latter is limited by the lack of a low dislocation density substrate that limits device area and an unfavorable, near unity, ionization coefficient ratio. In this paper we report on the development of III-Nitride/SiC separate absorption and multiplication avalanche photodiodes (SAM-APD) that combines high quantum efficiency, spectrally tunable, direct band gap III-Nitride semiconductor absorption region with a high gain and low noise SiC multiplication region. GaN/SiC APDs have been fabricated that exhibit gain > 1000 and responsivity of 4 A/W at 365 nm. We discuss the role of the large positive polarization interface charge density that occurs at the hetero-interface due to the large spontaneous polarization of the III-Nitride semiconductor on the electric field profile within and performance of these devices as well as the impact of lattice mismatch and strain.

8376-24, Session 6

The monolithic integration of high-speed Ge photo detector on SOI-based WDM receiver

W. Qian, D. Feng, H. Liang, J. Zhou, S. Liao, C. Kung, J. Fong, Y. Liu, J. Luff, R. Shafiiha, D. Lee, W. White, M. Asghari, Kotura, Inc. (United States)

We reported a novel, compact design of high speed Ge photo detector integrated with SOI based demultiplexer. The echelle grating demultiplexer is designed on a large cross-section SOI platform with low insertion loss and fiber coupling loss. The Ge photo detector is butt-coupled with the Si waveguide at horizontal direction to ensure a high speed operation. With the Ge detector size of only 0.8x15 um2, we achieved greater than 30 GHz high speed performance of the device. The results showed that the device speed is transit time limited and the detector takes the advantages of high electron and hole drift velocity of germanium material. The dark current of the detector is smaller than 0.3uA at -1v. The Ge detector is working at fiber optical communication wavelength range, which bring a excellent opportunity for monolithic integration of high speed Ge detector with high performance SOI based wavelength-division-multiplexing filter. This small footprint high speed Si-based WDM receiver can be merged in CMOS process and used for multichannel terabit data transmission with lower manufacturing cost.

8376-25, Session 6

FIB-assisted a-SiGe:H/a-SiC:H alloy analysis for ultra-low biased multispectral pixn sensors with enhanced color separation features and low-reflective ZnO:Al back-contacts

A. Bablich, K. Watty, C. Merfort, M. Boehm, Univ. Siegen (Germany)

Common security imaging CCD and CMOS systems are not able to distinguish colorimetrically between dangerous chemical substances, for example whitish powders. Hydrogenated amorphous silicon (a-Si:H) with profiled bandgaps can be found in solar cells to optimize the collection of incoming photons. We developed multicolor photodiodes based on a-Si:H with different spectral response characteristics for a reliable, fast, cheap and non-destructive identification of potentially dangerous substances. Optical and I-V measurements were performed to explore the effect of combining linear graded a SiC:H /a SiGe:H layers with low reflective ZnO:Al cathodes. We determined absorption coefficients and mobility-lifetime products (μ) of graded and non-graded absorbers to calculate the penetration depth of photons at different energies into the device structure. This set of parameters enables an optimization of the intrinsic layers so that charge accumulations are generated precisely at defined device depths. Significant color separation improvements could be achieved by using ZnO:Al cathodes instead of commonly used ZnO:Al/Chromium reflectors. As a result, we obtained multicolor diodes with highly precise adjustment of the spectral sensitivity reaching from 420 nm to 560 nm, reduced interference fringes and very low reverse bias voltage of maximum -2.5 V. Similar three terminal devices exhibit a shift from 440 nm to 630 nm by applying reverse voltages of -11 V at 560 nm. Present research efforts concentrate on further improvements of the absorption region to reduce the bias without affecting the optical sensor performance, using extensive bandgap engineering techniques.

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8377-01, Session 1

Advanced power and energy program at ARL

E. Shaffer, U.S. Army Research Lab. (United States)

No abstract available

8377-02, Session 1

Influence of nanosize and thermodynamics on lithium storage

P. Balaya, National Univ. of Singapore (Singapore)

Size reduction in nanocrystals leads to a variety of unexpected exciting phenomena due to enhanced surface-to-volume ratio and reduced length for the transport.[1,2] In this talk, we will consider some of those anomalous phenomena related to the effects of nano-size as well as thermodynamics on lithium storage behavior with a few illustrate examples.

Narrowly spaced nano-size of electrode materials results in rapid energy storage due to the reduction of the effective diffusion path. Nano-size also affects thermodynamics due to excess surface contributions giving rise to enhanced cell voltage of lithium batteries. In some cases this favors stabilizing metastable phases favoring high storage capacity. Thus nanocrystalline electrode materials exhibit high storage capacity as well as coulombic efficiency and in some cases high rate performances.

In this context, we will consider energy storage using nanocrystalline Li3V2(PO4)3 by insertion reaction and nanocrystalline Fe2O3 by conversion reaction and present our recent results. Li3V2(PO4)3 provides an ideal example for high potential cathode with excellent storage performance of 90 mAh/g at 30C at an average potential of 4.1V while Fe2O3 shows almost 90% reversible lithium storage with excellent cyclic performance using conversion reaction. Possible scenarios to consider such materials for developing high energy Li-ion battery that could be used for defenec applications would be presented.

References:

[1]. J. Maier, Nature Mater., 4 (2005) 805.

[2]. P. Balaya, Energy Environmen. Sci., 1 (2008) 645.

8377-04, Session 2

High-energy density electrode materials for next-generation lithium-ion batteries

A. Manthiram, The Univ. of Texas at Austin (United States)

Lithium-ion batteries have revolutionized the portable electronics market, but the energy densities of the current lithium-ion cells could not quite keep up with the rapid advances and miniaturization in electronics. Also, the adoption of lithium-ion batteries for transportation applications and stationary storage of electricity produced by renewables like solar and wind is hampered by high cost and safety concerns. Development of low-cost, safe electrode materials with high energy and power is critically needed to meet these challenges. With this perspective, after providing an overview of the pros and cons of the existing cathode and anode materials, this presentation will focus on the design and development of next generation of high energy density electrode materials. Specifically, the presentation will provide an overview of the recent developments in (i) high-capacity, high-voltage layered oxide cathodes, (ii) high-voltage spinel oxide cathodes, (iii) high-energy density sulfur-carbon nanocomposite cathodes, and (iv) high-capacity nano-engineered alloy anodes. Particularly, (i) novel synthesis approaches to obtain unique nanomorphologies, (ii) self-surface segregation of certain cations to the surface during synthesis processes to realize a robust electrode-electrolyte interface at high operating voltages, and (iii) surface modifications of cathodes and anodes with nanostructured materials in enhancing the energy and power will be emphasized.

8377-05, Session 2

Portable direct methanol fuel cells for practical applications: lessons learned and the road ahead

D. Chu, U.S. Army Research Lab. (United States)

There has been considerable interest in the development of polymer electrolyte membrane fuel cells (PEMFCs) for commercial applications during the last decade. Applications for this technology include small direct-power units for portable applications, medium power systems for battery charger, and larger power system for vehicle traction and resident. The efficient hydrogen/air PEM fuel cell systems are already in development to meet the need for portable applications. However, the main difficulty that remains to be overcome is the development of safe and compact units for hydrogen storage or the on-demand production of this gas. Therefore, direct methanol fuel cells (DMFCs) become an attractive alternative now. The development of improved hydrogen sources for hydrogen/air PEMFC and the development of membrane electrolyte and electrocatalysts for direct methanol fuel cells remain challenges. This presentation will focus on the technical challenges of membrane electrolytes, catalysts, fuel cell stacks and system issues for direct methanol fuel cell systems.

8377-06, Session 2

Lightweight carbon nanotube-based structural-energy storage devices for micro-unmanned systems

M. Rivera, D. P. Cole, Motile Robotics Inc. (United States) and U.S. Army Research Lab. (United States); M. G. Hahm, A. L. M. Reddy, R. Vajtai, P. M. Ajayan, Rice Univ. (United States); S. P. Karna, M. L. Bundy, U.S. Army Research Lab. (United States)

There is a strong need for small, lightweight energy storage devices that can satisfy the ever increasing power and energy demands of micro unmanned systems. Currently, most commercial and developmental micro unmanned systems utilize commercial-off-the-shelf (COTS) lithium polymer batteries for their energy storage needs. While COTS lithium polymer batteries are the industry norm, the weight of these batteries can account for up to 60% of the overall system mass and the capacity of these batteries can limit mission durations to the order of only a few minutes. One method to increase vehicle endurance without adding mass or sacrificing payload capabilities is to incorporate multiple system functions into a single material or structure. For example, the body or chassis of a micro vehicle could be replaced with a multifunctional material that would serve as both the vehicle structure and the on-board energy storage device.

In this paper we present recent progress towards the development of carbon nanotube (CNT)-based structural-energy storage devices for micro unmanned systems. Random and aligned CNT-polymer composite electrodes with varying degrees of flexibility are used as the primary building blocks for lightweight structural-supercapacitors. For the purpose of this study, the mechanical properties of the CNT-based electrodes and the charge-discharge behavior of the supercapacitor

devices are examined. Because incorporating multifunctionality into a single component often degrades the properties or performance of individual structures, the performance and property tradeoffs of the CNT-based structural-energy storage devices will also be discussed.

8377-07, Session 2

Molecularly tailored nanothermoelectrics and interfaces for energy harvesting and management

G. Ramanath, Rensselaer Polytechnic Institute (United States)

This talk will describe new strategies to realize inorganic nanomaterials and interfaces with novel electronic, thermal, thermoelectric and/or mechanical properties via molecularly-directed synthesis and modification for energy applications. I will demonstrate a new class of doped-nanothermelectrics obtained by the assembly of surfactant-sculpted nanocrystals synthesized by a scalable microwave-solvothermal approach. Besides providing the means to shape, size and protect the nanocrystals, the surfactant serves as a doping agent, thereby allowing the manipulation of electronic and thermoelectric properties. Sintered assemblies of the nanostructures exhibit up to 250% higher figure of merit than their non-nanostructured counterparts. While nanostructuring yields ultralow lattice thermal conductivities, sub-atomic-percent doping leads to single-crystal-like charge carrier mobilities with control over the majority carrier type, yielding high electrical conductivities and high Seebeck coefficients. The property enhancement mechanisms will be discussed based upon electron microscopy and spectroscopy. Our findings should enable transformative solid-state refrigeration and waste-heat harvesting technologies. The second part of my talk will describe new approaches to rationally manipulate the chemo-mechanical integrity and thermal conductance of interfaces using molecular nanolayers. I will show that introducing an organic nanomolecular monolayer can inhibit diffusion and lead to factorial increases in interfacial fracture toughness and thermal conductance. Spectroscopic probing and theoretical calculations indicate that the remarkable enhancements are due to strong interfacial bonding and overlapping low-frequency vibrational bands in the molecular layer and the materials comprising the interface. These results open up new ways for heat management in nanomaterials systems and devices.

8377-08, Session 3

Recent advanced in design and fabrication of on-chip microsupercapacitors

M. Beidaghi, C. Wang, Florida International Univ. (United States)

Development of miniaturized electronic systems has stimulated the demand for miniaturized power sources that can be integrated into such systems. Micro-supercapacitors with high power density can be coupled with energy harvesting devices to store the generated energy. Moreover, they can also be paired with micro-batteries to provide the peak power and improve the cycle lifetime. Recently, we have developed several types of micro-supercapacitors with different structural designs and active materials. Carbon-Microelectromechanical Systems (C-MEMS) with three dimensional (3D) interdigital structures are employed both as electrode material for electric double layer capacitor (EDLC) or as three dimensional (3D) current collectors of pseudo-capacitive materials. More recently, we have also developed micro-supercapacitor based on hybrid graphene and carbon nanotube interdigital structures. For all of the above systems effects of different experimental parameters on the performance of micro-supercapacitor cells are investigated by Cyclic Voltammetry (CV), Galvanostatic Charge-discharge and Electrochemical Impedance Spectroscopy (EIS). This talk will review recent advanced in design and fabrication of on-chip Microsupercapacitors.

8377-09, Session 3

Multifunctional structural composite batteries and supercapacitors

J. F. Snyder, E. Gienger, E. D. Wetzel, C. K. Xu, U.S. Army Research Lab. (United States)

The weight and volume of conventional energy storage technologies greatly limits their performance in mobile platforms. Traditional research efforts target improvements in energy density to reduce device size and mass. Enabling a device to perform additional functions, such as bearing mechanical load, is an alternative approach as long as the total mass efficiency exceeds that of the individual materials it replaces. Our research focuses on structural composites that function as batteries and supercapacitors. These multifunctional devices could be used to replace conventional structural components, such as vehicle frame elements, to provide significant system-level weight reductions and extend mission times. Our approach is to design structural properties directly into the electrolyte and electrode materials. Solid polymer electrolyte materials are being developed to bind the system and transfer load to the fibers while conducting ions between the electrodes. Carbon fiber electrodes provide a route towards optimizing both energy storage and load-bearing capabilities, and may also obviate the need for a separate current collector. Fiber surface treatments are being explored to optimize energy storage, including higher surface area fibers for supercapacitors and cathodic coatings to enable battery performance. The components are being integrated using scalable, cost-effective composite processing techniques that are scalable and amenable to complex part shapes. Metrics have been developed to correlate multifunctional performance with material properties as determined by standard mechanical and electrochemical testing procedures. Our results highlight the viability as well as the challenges of this multifunctional approach towards energy storage.

8377-10, Session 3

Development of biologically modified anodes for energy harvesting using microbial fuel cells

J. J. Sumner, U.S. Army Research Lab. (United States); R. Ganguli, Teledyne Scientific Co. (United States); B. F. Chmelka, Univ. of California, Santa Barbara (United States)

Biological fuel cells hold promise as an alternative energy source to batteries for unattended ground sensor applications due to the fact that they can be extremely long lived. This lifetime can be extended over batteries by scavenging fuel from the deployed environment. Microbial fuel cells (MFC) are one class of such sources that produce usable energy from small organic compounds (i.e. sugars, alcohols, organic acids, and biopolymers) which can be easily containerized or scavenged from the environment. The use of microorganisms as the anodic catalysts is what makes these systems unique from other biofuel cell designs. One of the main drawbacks of engineering a sensor system powered by an MFC is that power densities and current flux are extremely low in currently reported systems. The power density is limited by the mass transfer of the fuel source to the catalyst, the metabolism of the microbial catalysts and the electron transfer from the organism to the anode. This presentation will focus on the development of a new style of microbially-modified anodes which will increase power density to a level where a practical power source can be engineered. This is being achieved by developing a three dimensional matrix as an artificial, conductive biofilm. These artificial biofilms will allow the capture of a consortium of microbes designed for efficient metabolism of the available fuel source. Also it will keep the microbes close to the electrode allowing ready access by fuel and providing a low resistance passage of the liberated electrons from fuel oxidation.

8377-11, Session 3

III-V nitride semiconductors for solar fuels production

V. Parameshwaran, Stanford Univ. (United States) and Banpil Photonics, Inc. (United States); B. Clemens, Stanford Univ. (United States); R. W. Enck, C. Gallinat, A. V. Sampath, P. H. Shen, M. Wraback, U.S. Army Research Lab. (United States); S. Aloni, T. Kuykendall, Lawrence Berkeley National Lab. (United States)

Photoelectrochemical (PEC) cells are devices that can transform solar radiation into various fuels through a water decomposition process that transfers the incident energy from incident photons to the bonds of the resulting fuel. The most basic example of this process is the splitting of water into hydrogen and oxygen gas, from which the resulting hydrogen can be stored and used to power fuel cells. Within the PEC cell, the solar radiation absorption, electron-hole pair splitting, and photoelectrolysis reactions all occur within the electrode-electrolyte interface. As a result, engineering the electrode material and its interaction with the electrolyte is important in investigating and optimizing the solar-to-hydrogen conversion process in PEC cells.

We show that III-V nitride materials, which have been a focus within the optoelectronics and photonics industry for LED's, lasers, and solar cells, are promising candidates as a semiconducting material for both photoanodes and photocathodes within PEC cells. Additionally, the ability to engineer the electrode-electrolyte interface through bandgap and polarization engineering, nonuniform doping, quantum wells, and nanoscale growth opens up exciting directions for investigations and optimizations of the solar-to-hydrogen conversion process using III-V nitrides. We will describe our work in this area focusing on two candidate materials: indium gallium nitride (InGaN) and gallium phosphide nitride (GaPN).

8377-12, Session 3

Toward rechargeable magnesium batteries

K. A. Persson, R. Doe, G. Ceder, Pellion Technologies, Inc. (United States)

Magnesium-insertion batteries have many intrinsic advantages over lithium-ion technology. Magnesium ions (Mg2+) displace twice as much charge as lithium ions (Li+), and Mg2+ insertion can provide nearly double the cathode capacity over Li+ insertion if paired with a suitable transition metal redox couple. While an insertion anode is required for lithium, batteries containing Mg-metal anodes and Mg-based organometallic complex/organic solvent electrolytes demonstrate excellent cyclability [1,2]. The use of a Mg-metal anode results in significant gains in volumetric and gravimetric energy density compared to the lithium-insertion anodes, even if excess magnesium has to be used.

While rechargeable magnesium batteries, using Chevrel-based cathodes, paired with Mg metal anodes, have already demonstrated excellent cycle life [1], they are too low in energy density. Due to its small size and divalency, magnesium ions tend to exhibit lower mobility than Li ions and it is recognized that magnesium ion mobility will be a crucial property in evaluating possible insertion cathodes. Pellion Technologies is leveraging accelerated experimental synthesis, characterization, and testing with high-throughput computational materials design to identify novel magnesium insertion cathode materials. Using computational algorithms developed at Pellion, we have screened over 10,000 inorganic compounds for an optimal combination of properties such as voltage, structure, magnesium mobility, stability (e.g., phase diagrams), and density (i.e., volumetric energy). The resulting feedback loop between ab initio and experimental results is enabling Pellion to define an energy storage device to meet the needs of the 21st century.

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8377-13, Session 4

Pyroelectric thermal energy harvesting using MEMS-based resonant structures

S. R. Hunter, N. V. Lavrik, S. Rajic, P. G. C. Datskos, Oak Ridge National Lab. (United States)

The development of a new thermal energy harvester concept based on temperature cycled pyroelectric thermal-to-electrical energy conversion is outlined in this paper. The technique has the potential to generate useful amounts of electrical energy from thermal waste streams with temperature gradients of only a few degrees. The approach uses a resonantly driven pyroelectric capacitive bimorph cantilever structure that potentially has energy conversion efficiencies several times those of any previously demonstrated pyroelectric or thermoelectric thermal energy harvesters. The self-resonating bimorph cantilever structure used for fast temperature cycling in the energy harvester has been modeled using a finite element method. The effect of the structure material properties and system parameters on the frequency and magnitude of temperature cycling and the efficiency of energy recycling using the proposed structure have been investigated. Results show that thermal contact conductance and heat source temperature differences play key roles in dominating the cantilever resoantant frequency and efficiency of energy recycling. Thin film capacitors, formed from pyroelectric polyvinylidene difluoride-trifluroethylene P(VDF-TrFE) copolymer, were integrated with thermal bimorph MEMS cantilevers using standard clean room processes, and evaluated for potential thermal-to-electrical energy conversion devices. Individual millimeter sized self-resonating cantilever structures show thermal responsivities of 5-10µm/C and operating frequencies of 10-100 Hz. These energy harvesters produce appreciable (few µA) currents when interfaced between a waste heat source and a heat sink, and can be fabricated into scalable 2D arrays using well known microsystems fabrication techniques and materials, allowing significant amounts of electrical power to be generated. This paper will report on the modeling, fabrication and testing of test structures and single element devices that demonstrate the potential of this technology for the development of high efficiency thermal-to-electrical energy conversion devices.

8377-15, Session 4

Quantum-structured III-V energy harvesting devices: pathways to ultra-high conversion efficiencies

A. K. Sood, R. E. Welser, Magnolia Solar, Inc. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

Non-radiative recombination mechanisms typically lower the performance of compound semiconductor energy harvesting devices. However, recent advances in device structure design have allowed quantum well structures to begin reaching radiative limits. In this work, Jsc-Voc curves derived from illuminated current-voltage measurements on several different sets of InGaAs quantum well structures are characterized, and the underlying saturation current densities extracted. Analysis of the light IV characteristics suggests these quantum well devices are operating in a region of suppressed radiative recombination. These findings, coupled with other advances in the field, provide pathways for achieving ultra-high conversion efficiencies.

8377-16, Session 5

Flexible electronics and energy-related applications

A. B. Kaul, National Science Foundation (United States)

Flexible Electronics and Energy-related Applications (Invited)

Organic polymers are at the heart of most flexible electronic devices which rely on the mechanical flexibility of the organic polymer for maintaining electrical continuity after deformation. This talk will give an overview of our flexible electronics program at the National Science Foundation which will also include the use of such polymers for energy applications. Some of the energy-based applications that will be discussed in this talk are related to the use of organic polymers for photo-voltaics and light emitting diodes (LEDs) for solid-state lighting. While silicon photovoltaics is significantly more expensive compared to other forms of renewable energy technologies, such as wind and geothermal, organic, polymer-based materials have the potential to create the ultimate low-cost technology utilizing low-temperature and solution based processing. Such technologies are also compatible within a large-area, roll-to-roll processing platform. The main challenge here lies in increasing the efficiencies of such organic photo-voltaic cells, although progress has been made in this area recently. The other area that will be discussed in this talk involves the use of organic LEDs or OLEDs for solid state lighting applications which holds tremendous promise for solving the energy problem and protecting the environment given the growing concerns of rising CO2 emissions. Organic semiconducting LEDs are an attractive means for forming large area light sources and are particularly important for display technologies, as well as for low flux white light applications.

8377-17, Session 6

Nanostructured materials for thermoelectric energy conversion

A. Shakouri, Purdue Univ. (United States)

The field of thermoelectrics has progressed signficantly and is now growing because of recently demonstrated advances and strong global demand for cost-effective, pollution-free forms of energy conversion. Rapid growth and exciting innovative breakthroughs in the field over the last couple of years have occurred in large part due to a new fundamental focus on nanostructured materials. We review recent advances in low dimensional thermoelectric materials [1]. Using heterostructures and electron energy filtering, high power factor can be achieved. Differences between multilayers and embedded nanopaticles for increasing the thermoelectric power factor will be discussed [2]. Embedded nanoparticles can also be used to scatter mid and long wavelength phonons and reduce the lattice thermal conductivity with small impact on electrical transport. While the tradeoff in material properties can be reduced with nanoengineered structures, the overall efficiency/cost tradeoff has not been analyzed in detail [3]. In a waste heat recovery system, in addition to the thermoelectric device, the heat sink and the electrical and thermal resistances have to be co-optimized. A recent analytic theory is reviewed which shows the potential of thermoelectric waste heat recovery in a wide range of applications. Co-optimization of the thermoelectric module with the heat sink will permit minimizing the amount of material used in the system and reduce the overall energy payback.

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8377-18, Session 6

Scalable thermoelectric (TE) device technologies for power generation

P. M. Thomas, B. Cook, D. Stokes, G. Krueger, R. Venkatasubramanian, RTI International (United States)

Recent development efforts on thermoelectric (TE) power converters consisting of low-to-mid-temperature (25-400°C), and high-temperature (400-750°C) materials have achieved >60 Watts electrical power with a thermal-to-electric conversion efficiency of ~8%. This presentation will focus on thermoelectric devices fabricated from these materials, and also on cascaded power converters that enable the high power and efficiency to be obtained. In addition, work is underway to explore the use of more advanced low- to mid-temperature converters that have achieved over 10% efficiency on a single junction converter. The development of scalable TE devices with high efficiency provides increased opportunities for many applications, including portable power generation, waste heat recovery, and energy harvesting.

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8377-19, Session 6

Novel methodology to determine thermal conductivity of thermoelectric materials and comparison with device performance

J. Maddux, P. J. Taylor, U.S. Army Research Lab. (United States)

Accuracy of thermal conductivity measurements is an ongoing area of controversy in thermoelectric materials development. In this work, we demonstrate a novel steady-state method for characterizing thermal conductivity of bulk materials and devices under isothermal and near-isothermal conditions. The isothermal condition is achieved by exactly balancing Peltier heat flow against an externally imposed heat flow in the material. Under steady-state, isothermal conditions, heat flow in the material can be determined with high accuracy because external parasitic heat flows become negligible. We compare our results with conventional measurement techniques and also with measured thermoelectric device performance. Agreement between predicted and measured thermoelectric cooler performance is within about 2%. Results for thermoelectric power generators will also be discussed.

8377-20, Session 7

Advanced bulk thermoelectric materials and devices for energy harvesting

J. Bierschenk, Marlow Industries, Inc. (United States)

Thermal energy harvesting using the latest bulk thermoelectric devices offer unsurpassed scalability, enabling harvested power outputs that range from hundreds of microWatts to hundreds of Watts depending on the heat source and temperatures available. Traditional bulk thermoelectric devices made with Bi_2Te_3 materials, when properly optimized and matched with the latest low voltage step-up circuits can operate in stagnant air conditions with less than 5 C temperature differences between the heat source and ambient to provide an effective power source for wireless sensors and networks. The thermoelectrics in these systems must be matched both thermally to the heat sink and electrically to the load. Marlow has developed a new design methodology that optimizes these two interdependent design criteria to produce TE power sources that produce higher power output and operate at smaller temperature differences than competing technologies. The latest small scale TE power sources for wireless sensor applications will be presented.

Higher temperature thermoelectric devices enable harvesting power from higher temperature sources and at much higher power levels.

While significant research has been performed to develop a host of high temperature materials, very little work has been performed to translate the best suited high temperature materials into robust, manufacturable devices that can be utilized in a variety of DoD applications. Marlow's progress in developing high temperature bulk skutterudite materials and devices will be reviewed. Actual test data and applications will also be presented.

8377-21, Session 7

Development of PbTe material for advanced thermoelectric power generation

N. S. Prasad, NASA Langley Research Ctr. (United States); S. B. Trivedi, W. Palosz, R. Rosemeier, C. Rosemeier, Brimrose Corp. of America (United States); P. J. Taylor, U.S. Army Research Lab. (United States); J. Maddux, Brimrose Corp. of America (United States); J. Singh, The Pennsylvania State Univ. (United States)

Thermoelectric (TE) power generation is an increasingly important 'green' power generation technology. Major advantages include: no moving parts, low-weight, modularity, covertness/silence, high power density, low amortized cost, and long service life with minimum or no required maintenance. Despite low efficiency of power generation, there are many specialized needs for electrical power that TE technologies can uniquely and successfully address. Recent advances in thermoelectric materials technology have rekindled acute interest in thermoelectric power generation. We have developed single crystalline n- and p- type PbTe crystals and are also, developing PbTe bulk nanocomposites using PbTe nano powders and emerging field assisted sintering technology (FAST). We will discuss the materials requirements for efficient thermoelectric power generation using waste heat at intermediate temperature range (6500 to 8500 K). We will present our recent results on production of n- and p- type PbTe crystals and their thermoelectric characterization. Relative characteristics and performance of PbTe bulk single crystals and nano composites for thermoelectric power generation will be discussed.

8377-22, Session 7

Universal scaling relations for the thermoelectric power factor of semiconducting nanostructures

O. Rabin, J. E. Cornett, Univ. of Maryland, College Park (United States)

Computational models for the transport properties of nanostructured thermoelectric materials predicted vast improvements in the thermoelectric power factor (PF) values over bulk due to discretization of the electron density-of-states function as the result of confinement. We have developed a model that bridges bulk and nanostructure PF data. The model is analyzed in the framework of the relaxation time approximation, considering different scattering mechanisms. The model shows that the PF of nanowires and thin films in fact falls below the bulk value for most of the experimentally-accessible size range. Under the constant relaxation time approximation, universal scaling relations are obtained for all single-carrier semiconductors.

An improvement over bulk is only seen for film thicknesses and nanowire widths associated with quantization energies exceeding ~10 times the thermal energy. The power factor increases with size for most of the size-range investigated. With the consideration of specific scattering mechanisms with energy-dependent scattering times, the size-dependence of the PF of thin films and nanowires becomes material-specific. However, we find that the non-monotonic relationship between the thermoelectric PF and the system size is recurring in all systems studied. The effects of size, dimensionality, temperature, doping, impurity scattering, and phonon scattering in single-carrier semiconductors will be discussed.

8377-23, Session 8

Practical thermoelectric generators for automotive and industrial waste heat recovery

D. T. Crane, D. Kossakovski, V. Jovovic, J. LaGrandeur, E. Poliquin, Amerigon, Inc. (United States)

An innovative cylindrical thermoelectric generator (TEG) has been developed for waste heat recovery applications in automotive and industrial fields. The device has an integrated axial bypass channel, making it the highest volumetric power density system implemented in an automotive application thus far. Two devices have been built under a multi-year DOE program in collaboration with Ford and BMW. The TEGs have been installed in Ford and BMW vehicles and road tested. The presentation will discuss the device, design trade-offs and experimental data from bench and road testing.

In addition to automotive applications, a wide range industrial applications have high grade heat flows on the waste side. The cylindrical TEG can be used to convert wasted heat into electricity in cases where alternative technologies, however efficient they are, are not feasible.

8377-24, Session 8

Thermoelectric waste heat recovery from an M1 Abrams tank

D. Stokes, P. M. Thomas, M. J. Mantini, N. G. Baldasaro, R. Venkatasubramanian, RTI International (United States); M. D. Barton, Creare, Inc. (United States); C. Cardine, General Dynamics Land Systems (United States)

The addition of advanced sensors, targeting systems and electronic countermeasures to military vehicles has created a strategic need for additional electric power. By incorporating a thermoelectric (TE) waste heat recovery system to convert available exhaust heat to electricity, increased electric power needs can be met without reducing the energy efficiency of the vehicle. This approach allows existing vehicles to be upgraded without requiring a complete re-design of the engine and powertrain to support the integration of advanced electronic sensors and systems that keep the performance at the state of the art level.

RTI has partnered with General Dynamics Land Systems and Creare, Inc. on an ARL program* to develop a thermoelectric exhaust waste heat recovery system for the M1 Abrams tank. We have designed a reduced-scale system that was retrofitted to the tank and generated 80W of electric power on the vehicle operating on a test track by capturing a portion of the exhaust heat from the AGT-1500 gas turbine engine. The full-scale system design projections show power generation capability in the 10kW range with reasonable heat capture and heat rejection components. The design of the system and results from vehicle testing will be presented.

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8377-25, Session 8

Two-cavity MEMS capacitive power scavenger

J. Lin, J. Zhu, M. Sonje, Z. Feng, M. F. Almasri, Univ. of Missouri-Columbia (United States)

Novel 2×2 mm2 MEMS capacitive plates with two cavities (two capacitors) have been designed, modeled and fabricated for power harvesting by utilizing residual mechanical vibration in environment using electrostatic mechanism. The device is unique in the use of an innovative two-cavity design, and the use of electroplated nickel as the main structural material, which allows us to use both up and down directions

to optimize efficiency of power harvesting. The two-cavity design has achieved higher average power than conventional single cavity devices under a wide range of vibration frequencies and amplitudes based on the dynamic simulations involving consideration of symmetry breaking using Matlab. The device was designed and fabricated to vibrate without deformation, and with resonance frequencies of 800 Hz and lower using surface micromachining. The movable plate was suspended by removing the 30µm thick photoresist sacrificial layer using photoresist remover hot bath and slight sonic agitation. The second cavity was formed by fabricating a fixed plate and electroplating nickel/indium bonding pads on a second substrate. Both substrates were aligned and bonded together at 200oC. The initial testing for confirmation of successful suspension of the movable plate was implemented by measuring the change of capacitance with increasing applied voltage. The pull down effect was observed at around 13V. The devices were then fixed to a vibration stage for excitation, and wires bonded to an external conditioning circuit serving as a charge pump for testing. A maximum voltage step-up Vout/V0 = 3.6 was observed under an 800 Hz external forcing frequency.

8377-26, Session 8

MEMS capacitors with dual cavity for power harvesting

N. S. Yuksek, J. Lin, Z. Feng, M. Sonje, J. Zhu, M. F. Almasri, Univ. of Missouri-Columbia (United States)

The modeling, fabrication and testing of a two-cavity MEMS capacitor utilizing inertial forces from unwanted ambient vibrations has been performed. The device was designed with two air cavities and a thick movable metallic plate in order to increase the efficiency of the energy conversion from mechanical vibration. The moving plate was sandwiched between two fixed plates to construct a two cavity capacitor. The improved model verified the fact that that two-cavity model enhances the average output power by 2 to 5 times of a single cavity model. The device was designed with soft suspension beams and with a thick plate in order to acheive a natural frequency close to the ambient vibration frequencies. The FEM analysis showed that a thick electroplated nickel plate and beams can results in a natural frequency less than 1 kHz. The behavior of the plate under damping was also calculated using FEM analysis. The MEMS converters were fabricated using surface micromachining technology, nickel electroplating and photoresist sacricifial layer. The moving plate and suspension beams were grown on the photoresist sacrificial layer and Ni anchors. The structure was released by removing the photoresist sacrificial layers using photoresist strip remover. To form the top cavity, Ni pillars with sufficient thickness were grown by electroplating on another substrate followed by indium electroplating. The two substrates were then aligned and bonded together. A good control on the fabrication of two cavity MEMS capacitor is possible with the control of Ni growth thickness and control on the sacrificial layer thickness.

8377-27, Session 9

Recent development in thermoelectric materials

R. P. Tandon, Univ. of Delhi (India)

With the growing concern about the depleting energy resources, alternative methods of power generation such as thermoelectrics seems very lucrative, considering that more than half of all the energy generated by mankind is transformed into waste (heat).Recovering any part of the waste (heat) using thermoelectric materials would be extremely beneficial. The area of thermoelectrics is very significant in view of energy requirements both in civil and defense applications. Areas where energy supply is not easily maintained such as high altitudes,these materials can be boon.Recently many materials/material families have been explored to tap the potential of these materials to convert heat into energy such as BiTe, skutterudites, clathrates etc. BiTe shows maximum value of figure of merit, ZT=s2σ T/k, where T is absolute temperature, s is Seebeck coefficient, is electrical conductivity and k is thermal conductivity. Metal oxides have also been explored such as ZnO, CaMnO3, In2O3: Ge, Zn1-x-yAlxTiyO for suitable figure of merit. An elaborate overview of these materials will be presented along with our new findings on Ca3Co4O9ceramics. In the present work,Ca3Co4O9 doped with rare earths have been synthesized via solid state reaction method. The material has also been synthesized by sol gel technique which yielded nano-sized grains with improved texture which simultaneously enhanced Seebeck coefficient, electrical conductivity and thermal resistivity bringing about great enhancement in figure of merit ZT (~0.45 at 6000C). This material turns out to be highly efficient thermoelectric material for conversion of waste heat directly into electricity.

8377-28, Session 9

Alpha Schottky junction energy source

M. S. Litz, S. L. Henriquez, J. J. Carroll, U.S. Army Research Lab. (United States)

Isotope batteries present solutions for long-lived low power sources. Compact sensors, and electronic circuit boards can be powered for the lifetime of infrastructure. Alpha sources are considered in this paper for two reasons. The limited distance of energy absorption in materials (~20um) makes radiation shielding easier, even in the midst of potential bremsstrahlung generated during the slowing down process. Therefore, safety concerns are mitigated. The high energy (~5MeV) per particle exceeds the energy of many practical beta and gamma emitters. This permits higher power output compared to beta and gamma emitters, with less total activity of the isotope. The alpha energy is converted primarily to low-energy (<1kV) electrons which do contribute to electric current after additional slowing down in the diamond-like semiconductor. Damage to materials from the alphas limits the practical use. Diamond-like materials have a high radiation tolerance, related to the wide-band-gap of the material. A Schottky Barrier Diode (SBD) geometry is created from an alpha impregnated metal-contact-layer, on a diamond-like crystal. A power source is proposed that takes advantage of the radiation damage tolerance of diamond, combined with the short range of the alpha radiation. The internal field of the SBD creates a current through the diode from electron-hole pairs created by alpha bombardment in the SBD depletion region. Device design parameters, circuit model results, and calculations of the expected current are described.

8377-29, Session 9

Emerging applications and markets for thin-film thermoelectric energy harvesting

J. J. Mundell, Nextreme Thermal Solutions, Inc. (United States)

Advances in distributed sensors and sensor networks have led to an increased interest in the use of renewable power sources to replace or augment existing power systems. The use of heat is an attractive source of energy for many low-power sensor applications. Thermobility is a new power generation technology that uses innovative, solid-state thin-film thermoelectric technology to convert heat into electricity for a variety of self-contained, autonomous systems. The use of microscale thin-film thermoelectrics is creating new applications and markets for energy harvesting ranging from motion sensors in buildings and integrated bearing condition monitoring in turbine engines; to data acquisition in plumbing and hands-free faucets. Energy harvesting using thermal energy can substantially increase product lifetimes in the field and reduce the total cost of ownership by eliminating the prohibitive cost of battery replacement for decades of maintenance-free operation.

8377-30, Poster Session

Solar-powered, ad-hoc, wireless-sensor network for border surveillance

J. He, R. A. Norwood, M. Fallahi, N. N. Peyghambarian, College of Optical Sciences, The Univ. of Arizona (United States)

Wireless sensor networks (WSNs) have emerged as a means of providing automated monitoring, target tracking, and intrusion detection. Solar-powered WSNs that adopt innovative sensors with low power consumption and forefront networking technologies are significant for DHS by providing rapidly deployable situational awareness and effective security control at the border at low cost. However, the constraints in sensor nodes, such as limited processing power, memory, and situation-aware power management, hinder the wider deployment of sensor nodes as practical solutions and pose the key research challenge.

In this paper, we introduce a prototype of our new solar-powered WSN platform for border security and demonstrate a solar-powered ad-hoc WSN system that mitigates these constraints for border surveillance. In our solar-powered WSN, heterogeneous sensing components are integrated to enable multi-functional sensing functionalities, including image capturing, voice recording, motion detection, vibration sensing, and environmental monitoring. Sensor nodes are powered by either lithium batteries or solar panels that are controlled by an advanced power management module.

We consider practical issues in WSNs, including sensing environment classification, survivability under harsh weather conditions, and efficient solar energy harvesting. To maximize the operating lifetime of the sensor network, we designed an optimized situation-aware algorithm based on advanced machine learning techniques. Sensor nodes will intelligently switch to different modes based on different situations. The embedded SD card is used to provide storage space for data aggregation and local processing.

Experimental results show the improvement of our algorithm. Important findings from field experiments will also be also presented in the paper.

8377-31, Poster Session

DNA: multiple architectures for use in electronics applications

A. S. Finch, U.S. Army Research Lab. (United States)

A methodology that allows for the coupling of biology and electronic materials is presented, where double stranded DNA will ultimately serve as a template for electronic material growth. Self-assembled DNA structures allow for a variety of patterns to be achieved on the nanometer size scale that is difficult to achieve using conventional patterning techniques. DNA self assembly under non-aqueous conditions has yet to be presented in literature, and is necessary if unwanted oxidation of certain electronic substrates is to be avoided. Solubilization of the DNA in non-aqueous solvents is achieved by replacing charge stabilizing salts with the surfactant cetyl trimethyl ammonium chloride (CTAC).

Herein, the procedures for the creation of self-assembled DNA nanostructures in aqueous and non-aqueous media are described, and these structures are subsequently deposited (drop cast, spin cast, and physically adsorbed) onto freshly cleaved mica or silicon wafers. The DNA architectures are characterized either in solution (circular dichroism spectroscopy (CD)) or on the surface (ellipsometry and AFM). These studies illustrate the retention of DNA hierarchical structure under both conditions and this data will be presented by observing the structures using AFM imaging and CD spectroscopic studies.

8377-32, Poster Session

A new microwave-based control system for emulsion-layer removal in oil tanks

M. Meribout, The Petroleum Institute (United Arab Emirates)

With the continuous depletion of oil reservoirs, emulsion layer in tanks reaches up to 30 % of the total volume of oil. Thus, online extraction of pure oil from the emulsion layer is getting increasingly important for oil producing companies. This paper proposes a new control system to remove the emulsion layer which usually appears in crude oil tanks between single phase liquids (e.g. water and oil phases). A built-in antenna was designed to generate heat into a predefined location of the emulsion layer. This location is determined based on the oil-water content corresponding to the maximal heating efficiency: Less evaporation of oil components and fast heat propagation. A Numerical model of the tank and its content using multiphisics Comsol software was built to help designing the RF antenna and to understand the behavior of microwaves. In addition, a prototype holding the array of sensors, as well as the designed antenna and the corresponding actuation unit were built and used to handle various experiments. The obtained simulation results were found to match the ones obtained from experimental results.

8377-33, Poster Session

An electric emergency system using energy harvesting sources

E. I. Ortiz-Rivera, C. I. Gonzalez, Univ. de Puerto Rico Mayagüez (United States)

Development of new technologies on systems using alternative energy is important for the world with specific applications. The goal of this paper is to propose a high efficiency energy harvesting system capable of supply and control the power to a critical load on emergency situations. To overcome this problem, a system using only one source of energy, such as thermoelectric generator or photovoltaic panel, may be a good option to this particular situation. The thermoelectric generator is the prefer option for the type of energy source because of its power property, has a compact size and is not dependent direct proportionally to the sun comparable to the photovoltaic panel. It proposed an electric emergency generator system using a thermoelectric energy harvesting source to control the velocity of a three phase induction motor useful for emergency situation. The results of the prototype system have been with an acceptable efficiency and a good control of the motor. The proposed system compare different types of DC/DC converters and inverters, step-down transformers, appropriate thermoelectric energy harvesting sources, to improve the power supply under an emergency situation.

8377-34, Poster Session

An integrated thermoelectric harvesting system for sensor applications

E. I. Ortiz-Rivera, Univ. de Puerto Rico Mayagüez (United States)

This paper proposes a monolithic integrated thermoelectric energy harvesting system that can serve as platform for future wireless sensor nodes. This is possible by the development of a complete thermoelectric scavenging system on a chip to power remote wireless sensors. The proposed approach merges a Maximum Power Point Tracking scheme based on the Linear Reoriented Coordinates Method (LRCM) technique along with low-power and floating-gate IC design techniques in the design of a thermoelectric powered system. Hardware implementation of the LRCM will allow for on-chip optimal energy transfer. Low-voltage and low-power operation is enabled through the use of floating-gate design techniques. First, energy conversion is performed with an array of thermoelectric generators. Second, optimal energy transfer is enabled through the implementation of a maximum power point tracking technique based on the Linear Reoriented Coordinate Method. Next, the stored voltage is then increased with a charge-pump circuit. Finally the output voltage is regulated for load and power supply changes. The proposed thermoelectric energy harvesting system has been demonstrated through simulations the feasibility of the proposed design. Current and near future work will include the integration and circuit simulation of the complete system to have concrete results for presentation and the eventual fabrication of the chip.

8377-35, Poster Session

A maximum power point tracking for solar cells using an analog design control system for a low-voltage sensor applications

E. I. Ortiz-Rivera, Univ. de Puerto Rico Mayagüez (United States)

This work addresses the use of a Maximum Power Point Tracking (MPPT) for solar cells using an analog design as the control circuit for a Low-Voltage Sensor Applications. The Maximum Power Point Tacking strategy is based on the optimal duty cycle of the dc-dc converter to transfer the maximum power to the load (i.e. sensors). The analog control scheme is designed to be implemented in different power limited sources and on different power ranges. A buck converter is designed to operate in dimmer mode operation and MPPT mode operation to regulate the voltage and power supplied to the low-voltage sensors. The design was simulated using tools like MatLab®, Simulink®, and Multisim®. The simulations were validated experimentally on a breadboard a used for turning a lamp using a solar cells array.

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8378-01, Session 1

Past, present, and future of BSE imaging in the SEM

O. C. Wells, L. M. Gignac, M. S. Gordon, IBM Thomas J. Watson Research Ctr. (United States)

In this talk, we will describe developments in backscattered electron (BSE) imaging in the scanning electron microscope (SEM) since the pioneering work of Charles Oatley, Dennis McMullan, and Kenneth Smith in the 1950's. Recent work on BSE imaging with very high energy (100's of KeV) electron beams, such as the inspection of voids in metallurgy under thick dielectrics in semiconductor packaging will be presented. Finally, we will look toward the future of BSE imaging in terms of the SEM's, detectors, and application areas.

8378-02, Session 1

Faults and foibles of quantitative EDS

D. E. Newbury, National Institute of Standards and Technology (United States)

Scanning electron microscopy with energy dispersive x-ray spectrometry (SEM/EDS) is a powerful and flexible elemental analysis method that can identify and quantify elements with atomic numbers > 4 (Be) present as major constituents (where the mass concentration C > 0.1, or 10 weight percent), minor (0.01< C < 0.1) and trace (C < 0.01, with a minimum detectable limit of ~ 0.001, analyte and matrix dependent). SEM/EDS can select specimen volumes with linear dimensions from ~500 nm to 5 m depending on composition (masses ranging from ~10 pg - 100 pg) and can provide compositional maps that depict lateral elemental distributions. Despite the maturity of SEM/EDS, which has a history of more than 40 years, and the sophistication of modern analytical software, the method is vulnerable to serious shortcomings that can lead to incorrect elemental identifications and quantification errors that significantly exceed reasonable expectations. This paper will describe shortcomings in peak identification procedures, limitations on the accuracy of quantitative analysis due to specimen topography or failures in physical models for matrix corrections, and quantitative artifacts encountered in x-ray elemental mapping. Effective solutions to these problems are based on understanding the causes and then establishing appropriate measurement science protocols. NIST DTSA II and Lispix are open source analytical software available free at www.nist.gov that can aid the analyst in overcoming significant limitations to SEM/EDS.

8378-03, Session 1

Quantitative mechanical mapping at nanometer scale

C. Su, Bruker Nano Inc. (United States)

Mechanical property characterization, such as elasticity, hardness, adhesion, and fracture toughness, with the spatial resolution of a nanometer was recognized a decade ago as a grand challenge for nanotechnology. Atomic force microscope (AFM) interrogates the samples mechanically and provides atomic resolution in most commercial systems. The technology was a natural candidate for nanomechanical mapping. However, uncertainty factors such as tip geometry characterization, force calibration and control, and ultimately, the models used to compute material properties, substantially complicate the measurements. This renders even qualitative extraction of critical mechanical properties a challenging task. Many advances have been made in the last decade. A series of calibration methods for force and tip geometry has been developed. Various tip-sample interaction models were implemented and validated through the fitting of constitutive equations and finite element simulations. The technology of mechanical mapping also experienced great advancements. The time scale of tip-sample interaction now spans from tens of nanoseconds to seconds, force control from a few piconewtons to micronewtons, and spatial resolution reaching sub-nanometer scales in stiffness mapping. AFM has become a unique mechanical measurement tool, with a large, dynamic range (1kPa to 100 GPa in modulus) and the flexibility to integrate with other physical property characterization techniques in versatile environments. The methods of mechanical mapping have also evolved from force volume to multiple-frequency based dynamic measurements using Tapping Mode and contact resonance. Recently, high-speed and real-time control of peak force in Lenard-Jones interactions has led to a fundamental change in AFM mapping, providing unprecedented resolution and potential for quantifying mechanical properties. A broad scope of materials was studied, ranging from live cells to nano-composites and semiconductor devices.

8378-04, Session 1

Does your SEM really tell the truth?

M. T. Postek, National Institute of Standards and Technology (United States)

Quantitative measurements with any scientific instrument require more care and understanding than one might first assume. The physical principles that dominate quantitative measurements must be fully understood and accounted for in the measurement. For example, in optics, the effects of diffraction must be overcome; in scanned probe microscopy, the scanned probe tip shape must be considered and in scanning electron microscopy, the generation of the measured signal, beam diameter, sample charging and the electron beam-specimen interactions all must be considered. If one assumes everything is correct without carefully checking, erroneous data can result. The Scanning electron microscope is a primary tool in many phases of research, development and manufacturing for over 50 years. It is highly likely that he common question: "how big is that?" specimen or structure currently being imaged in the instrument has been asked since the first micrograph was ever recorded. The quality of that answer has improved tremendously over the past few years, especially since these instruments are being used as a primary tool on semiconductor processing lines to monitor the manufacturing process. Over the past 20 years or so, the semiconductor industry has invested a great deal of R&D money to improve the performance of these instruments and all users have benefitted from this investment especially where measurements are concerned This presentation will discuss some of the issues associated with imaging and metrology with the SEM.

8378-21, Session 1

Nanoscale chemical composition mapping of polymers at 100nm spatial resolution with AFM-based IR spectroscopy

K. Kjoller, C. B. Prater, M. Lo, Anasys Instruments (United States); A. Dazzi, Univ. of Paris-Sud-XI (France); R. Shetty, Anasys Instruments (United States)

Atomic force microscope (AFM) and IR Spectroscopy have been in combined in a new technology platform (AFM-IR) to map nanoscale chemical, structural and thermo-mechanical variations in polymers and other samples. The AFM-IR technique illuminates the sample with light from an infrared laser and measures the IR absorption of this light on a sub-wavelength scale using the tip of an AFM by detecting local thermal expansion of the sample. AFM-IR can be used both to obtain absorption spectra at arbitrary points and to spatially map IR absorption at selected wavelengths. Simultaneous measurement of the AFM cantilever's contact resonance frequency as excited by the IR absorption provides a complementary and simultaneous measurement of sample stiffness. The AFM-IR techniques have been used to chemically identify individual chemical components in polymer nanocomposites and multilayer films with spatial resolution as high as 100 nm. Using self-heating AFM cantilever probes we have been able to locally modify the state of a semicrystalline polymer and observe the resulting change in IR absorption spectra on the nanoscale. By changing the polarization of the incident laser source, we have also mapped variations in molecular orientation in individual sub-micron polymer fibers.

8378-05, Session 2

Introduction to chemical warfare agents

J. P. Petrali, U.S. Army Medical Research Institute of Chemical Defense (United States)

Although there are historical accounts of the use of primitive chemical weapons in early warfare, modern chemical warfare, as we know it, was introduced as a viable alternative to conventional warfare during World War 1. During that conflict, weaponized chemical agents were designed to harm combatants and to render battlefield territories uninhabitable and were especially utilized to defeat the stalemate of trench warfare. Since both sides of the conflict engaged in the accelerated production of chemical agents for weaponization and dispersal, World War 1 became eventually known as the "war of chemists". Although there are five classes of weaponized chemical agents, i.e. vesicating agents, systemic agents, pulmonary agents, incapacitating agents and nerve agents, the one agent that resulted in the most casualties and, in the most territories surrendered, was the vesicating agent mustard gas. Mustard gas, chemically recognized as sulfur mustard, was responsible for over 70% of the 1.3 million chemical casualties of that war. Since then, continuing incidents of the isolated use of chemical agents by combatants, multiple accidental exposures and the threat of terrorism have now directed laboratory-based studies toward development of effective countermeasures. This presentation and others in this session will review the known pathogenesis of chemical agent-induced injuries and will address the laboratory investigations now on-going toward the mitigation and eventual elimination of the medical consequences of chemical warfare.

DISCLAIMERS: The views expressed in this abstract are those of the authors and do not reflect the official policy of the Department of the Army, Department of Defense, or the U.S. Government. The experimental protocols used in these studies were approved by the Animal Care and Use Committee at the United States Army Medical Research Institute of Chemical Defense and all procedures were conducted in accordance with the principles stated in the Guide for the Care and Use of Laboratory Animals and Animal Welfare Act of 1966 (P.L. 89-544) as amended. This research was supported in part by NIH and the Defense Threat Reduction Agency-Joint Science and Technology Office, Medical S&T Division.

8378-06, Session 2

Tissue injury due to mustard gas exposure: cellular and molecular mechanisms

R. Ray, B. Keyser, D. Andres, B. Benton, A. Grigorovitch, D. Anderson, W. Holmes, U.S. Army Medical Research Institute of Chemical Defense (United States); C. Rosenthal, D. S. Rosenthal, Georgetown Univ. School of Medicine (United States)

Sulfur mustard (bis-(2-chloroethyl) sulfide; SM), which is commonly known as mustard gas, is both a military threat agent and a civilian terrorism agent. In addition to severe skin blistering, SM causes epithelial damage to eyes and respiratory tract. Our in vitro studies using cultured normal human epidermal keratinocytes (HEK) and airway epithelial cells (AEC) have shown that SM-induced apoptosis occurs via both intrinsic mitochondrial and extrinsic death receptor (DR) pathways. Using a human skin grafted onto nude mouse model, we showed that microvesication and tissue injury due to SM can be prevented by blocking the DR pathway via expressing a dominate-negative Fas-associated death domain (FADD-DN) protein. Moreover, we showed that the DR pathway is the predominant mechanism of SM-induced apoptosis in human AEC. These observations led us to a detailed study of the roles of both the mitochondrial and the DR pathways, particularly the cross-talk between them. The effects of the apoptotic pathway-specific caspase (cysteine protease) inhibitors revealed the cross-talk between the pathways; these results were confirmed by the small interfering RNA (siRNA) molecular approach. Our results showed that apoptotic cell death due to SM is predominantly via a death receptor pathway that utilizes a feedback amplification mechanism involving both the mitochondrial and the DR pathways. Our in vivo studies using a rat SM inhalation model have produced results supporting our in vitro observations. These results explain the cellular, molecular and pathophysiological mechanisms of mustard gas injury and, moreover, provide possible strategies for medical countermeasures.

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8378-07, Session 2

Ultrastructural characterization of the acute and delayed-onset injury in rabbit corneas following exposure to sulfur mustard vapor

P. McNutt, A. Adkins, M. Nelson, A. Swartz, K. Tuznik, M. Lyman, T. Hamilton, U.S. Army Medical Research Institute of Chemical Defense (United States)

Although acute corneal lesions resulting from ocular exposure to sulfur mustard (SM) often resolve clinically, a delayed-onset mustard gas keratopathy (MGK) subsequently develops in 16% of those that receive at least 100ug/min/m3 of SM vapor. The etiology of this delayed injury is unknown, but pathogenesis typically involves progressive corneal degeneration and results in severely impaired vision. We used transmission electron microscopy (TEM) to evaluate ultrastructural changes associated with MGK in a rabbit ocular model of SM-induced MGK. Ultrastructural analysis of corneas at 2-8 week post exposure demonstrates that the delayed injury involves persistent epithelial and stromal edema and severe cyclical disorganization of the basement membrane zone (BMZ), whereas healthy appearing BMZ was present in resolved (non-MGK) corneas. This is the first correlation between ultrastructural and clinical aspects of the acute and recurrent SM ocular

injury, linking architectural changes in corneal epithelium, basement membrane and stoma with onset of MGK sequelae.

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8378-08, Session 2

Progression of brain injury following exposure to the chemical warfare nerve agent Soman: involvement of different brain cells and neuroinflammation

R. Kan, J. A. Leuschner, D. F. Scutella, T. T. Dao, S. W. Kaski, C. R. Braue, E. A. Johnson, U.S. Army Medical Research Institute of Chemical Defense (United States)

The present study investigated the time-course of brain injury and correlated the injury progression with the response of neurons, astrocytes and microglial cells following acute soman (GD) intoxication. The magnitude of MAP-2 loss was correlated with neuronal injury as indicated by decreased neuronal nuclear protein (NeuN) immunohistochemistry and increased fluoro-jade B positive neurons. Glial fillbrillary acidic protein (GFAP) staining was increased during the first 6 hr after the onset of seizures and decreased after 12 hr within the necrotic core. In addition, after 24 hr, GFAP immunoreactivity surrounding the lesion became more intense, and astrocytic fibers were arranged in a palisade-like pattern directly adjacent to the lesional area. Iba1 immunohistochemistry revealed a progression of microglia activation with multi-step phenotypic changes. Luminex immunoassay revealed that the expression of inflammatory mediators, such as MIP-1α, TNFα, IL-1α, IL-1β and GRO KC was coincident with the severity of brain damage. Double-labeling studies showed that the acute-phase response cytokines, particularly IL-1α and IL-1β, are expressed in activated and dystrophic microglia. These observations suggest that 1) exposure to GD causes extensive neuronal damage and reactive gliosis and 2) activated microglia may play a key role in contributing to neuroinflammation causing secondary tissue injury. Modulating neuroinflammation may be a logical neuroprotective scheme to reduce the severity of brain injury after chemical warfare nerve agent intoxication.

DISCLAIMERS: The views expressed in this abstract are those of the authors and do not reflect the official policy of the Department of the Army, Department of Defense, or the U.S. Government. The experimental protocols used in these studies were approved by the Animal Care and Use Committee at the United States Army Medical Research Institute of Chemical Defense and all procedures were conducted in accordance with the principles stated in the Guide for the Care and Use of Laboratory Animals and Animal Welfare Act of 1966 (P.L. 89-544) as amended. This research was supported in part by NIH and the Defense Threat Reduction Agency-Joint Science and Technology Office, Medical S&T Division.

8378-09, Session 2

Development and efficacy of cwa countermeasures: sulfur mustard

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For the past fifteen years the international research community has conducted a basic and applied research program aimed at identifying a medical countermeasure against vesicant agents. The primary emphasis of this program has been the development of a medical protection against sulfur mustard and its cutaneous pathology--blister formation. Besides the work on a medical countermeasure, significant research has been conducted on the development of topical skin protectants and on medical strategies for wound healing. This review will focus our understanding of the pathophysiological mechanisms of mustard injury that has come from this research. Our laboratory utilizes fluorescence technology along with light microscopy image analysis, flow cytometry, and multiplex assay systems to identify biomarkers of mustard intoxication and evaluate potential medical countermeasures to protect against the insidious effects of this agent on human tissue. While great strides have been made through these investigations, the complexity of the mustard insult demands that further studies extend the inroads made and point the way toward better understanding of cellular and tissue disruptions caused by sulfur mustard.

The opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the U.S. Army or the Department of Defense.

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8378-10, Session 3

Characterization of a New Traceable Metrology AFM at NIST

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The National Institute of Standards and Technology (NIST) has a multifaceted program in atomic force microscope (AFM) dimensional metrology. A major component of this effort is the development of custom AFM metrology instruments.

The first generation instrument, called the calibrated AFM (C-AFM) [1,2], was developed in the 1990s. It was designed and constructed with displacement metrology for all three axes traceable to the 633 nm wavelength of the iodine-stabilized He-Ne laser. Due to obsolescence, however, the C-AFM was recently decommissioned.

Through a partnership with BrukerNano, NIST will acquire a replacement system - called the traceable AFM (T-AFM). The T-AFM will incorporate interferometric displacement metrology an order of magnitude more precise than was used in the C-AFM. It will be based around a commercially available TITANOS platform - capable of measuring sample sizes up to 300 mm wafers and will operate in both contact and intermittent contact modes.

This paper will report on the development of the T-AFM and the results of initial performance testing.

1. J. A. Kramar, R. Dixson, N. G. Orji, “Scanning Probe Microscope Dimensional Metrology at NIST,” Meas. Sci. Technol. 22, 024001 (2011).

2. R. Dixson, N. G. Orji, J. Fu, M. Cresswell, R. Allen, W. Guthrie, “Traceable Atomic Force Microscope Dimensional Metrology at NIST,” SPIE Proceedings Vol. 6152, 61520P-1-11 (2006).

8378-11, Session 3

Atomic force microscope cantilevers as encoder for real-time displacement measurements

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Cantilevers of Atomic Force Microscopes (AFM) allow with their fine tip high-resolution- imaging of surfaces. In the PTB we have investigated the use of pairs of cantilevers for encoding displacement measurements by pairing with a 1D optical grating of well-defined pitch to determine the displacement of a moving stage with high-resolution for forward and backward movements.

If one AFM cantilever is used as encoder when paired with 1D sinusoidal/rectangular/trapezoidal grating with the pitch of P (nm) as the reference, the decoding principle is based on direct count of integer periods I plus calculation of two fractional parts of such periods fs standing at the beginning and fe at the actual position in the encoded signal corresponding to a given path of displacement will be S=(fs+I+fe)*P(nm) .

Due to the noise and small deviation of single points on the artifact a filter was necessary to ensure the accurate implementation of this decoding process. A cross-correlation technique has been employed to filter 1D grating encoded signal Y(n) in real time: A half sinusoidal waveform template is found very efficient and correct to filter 1D any waveform grating encoded signal by cross-correlating with it .

In the case of using two AFM cantilevers to encode a 1D sinusoidal grating pattern with the pitch of P (nm) as the reference, the distance between two cantilever tips has to be preset in such a way that the two 1D sinusoidal grating position-encoded signals Y1(n) and Y2(n) have a quadrature phase (90°) shift. By directly unwrapping the phase between two encoded signals, forward and backward displacements in the direction cross the 1D grating lines can be detected and measured in real time. Additional differentiation process of the signals is necessary to remove effects due to the tilt and offset .

It will be presented that the set-up of AFM cantilevers encoder and experimental details of the filtering and displacements measurement by using AFM cantilever as encode paired with 1D gratings of various pitch down to 80 nm.

8378-12, Session 3

Development of a laser interferometer for implementation in a metrological scanning probe microscope

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Laser interferometers are key components of metrological scanning probe microscopes (mSPM) developed and operated in national measurement institutes around the world to provide traceable dimensional measurements at the nanoscale. This is due to the remarkable sensitivity of laser interferometry and the simplicity of calibrating the interferometer while providing traceability to primary standards. At the National Measurement Institute Australia we have developed a novel, high performance heterodyne laser interferometer for use in an mSPM.

Our interferometer uses a field-programmable gate array (FPGA)-based digital phasemeter, utilizing two phase locked loops (PLLs): one for the reference field and the other for the signal field. Each PLL is implemented on a common FPGA platform, therefore ensuring timing coherence, long-term stability, and well-matched signal paths, allowing more than 70 dB of common-mode noise suppression. This phase-meter implementation is able to track large, high-frequency signals and exhibits no inherent cyclic error. The all-digital phase meter system is versatile, allowing the PLL filters and gain bandwidth to be optimized for the particular measurement task. It is also readily scalable to a multichannel system such as an mSPM. We have demonstrated an optical phase sensitivity of 5 μrad/√(Hz) and a resulting displacement sensitivity of 0.25 pm/√(Hz).

We have developed a synthetic heterodyne laser source that is both tunable and minimizes cyclic error arising from cross-coupling within the source laser. In addition, we have developed a convenient and precise means of quantifying cyclic error and have used this technique to characterize the cyclic error contribution of a number of common interferometer components. This knowledge has enabled us to optimize the interferometer configuration to reduce the total cyclic error to 50 pm, and operate commercial interferometers with less than 130 pm of cyclic error.

8378-14, Session 3

High throughput and non-destructive sidewall roughness measurement using 3-dimensional atomic force microscopy

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As the feature size in the lithography process continuously shrinks, accurate critical dimension (CD) measurement becomes more and more important. With the smaller features, the sidewall increasingly influences the CD measurement and characterizing the CD of a structure becomes more critical on the nanoscale. For the state-of-art extreme ultraviolet (EUV) lithography development, the characterization of the sidewall roughness of the photoresist and the study of how this sidewall roughness of the photoresist will be transferred into the underneath layers during etching is a critically important but yet very challenging task.

Over the past a few years, atomic force microscopy (AFM) has become a powerful tool for accurate nanometrology. However, because most AFMs operate in a top-down configuration, AFM has limited access to the sidewall; this is especially true when the sidewall angle is near or greater than 90 degrees. Some temporary solution has been used to characterize the sidewall roughness by mechanically cleaving the sample and then imaging the sidewall with AFM on tilted sample. But this method only works for large features and it is destructive.

Recently, we have introduced a new 3D AFM imaging technology using tilted Z scanner. In this new 3D AFM configuration, the Z scanner is separate from the XY scanner. When the Z scanner is tilted to one side with respect to the XY scanner, where the sample is attached, the AFM tip attached to the Z scanner is tilted too. By this mean, the sharp end of the tip can easily reach the sidewall of the sample features; even the sidewall angle is close or over 90 degree. This new technology is extremely powerful for sidewall roughness measurement. Because conical ultra sharp tip is used, this 3D AFM imaging technology can achieve same high resolution as regular AFM, even on the sidewall. By scanning along the feature, only a few scan lines are needed to accurately measure the sidewall roughness, and this 3D AFM technology has very high throughput for sidewall roughness measurement. This 3D AFM technology does not require any special sample preparation, and it is non-destructive. Because of it is high resolution, high throughput, and non-destructive, this new technology can be potentially used for in-line metrology for production.

In this paper, we have also studied the throughput and repeatability of this new 3D AFM technology as a metrology solution for sidewall roughness.

8378-15, Session 4

Hybrid metrology for critical dimension based on scanning methods to answer to the semiconductor industry requirements

J. Foucher, CEA-LETI (France)

Introduction of new material stacks, more sophisticated design rules and complex 3D architectures in semiconductor technology has led to major metrology challenges by posing stringent measurement precision and accuracy requirements for various critical dimensions (CD), feature shape and profile. Current CD metrology techniques being used in development and production such as CD-SEM, scatterometry and CD-AFM, individually have intrinsic limitations that must be overcome. The approach of hybrid automated metrology seems necessary. Using multiple tools in unison is an adequate solution when adding their respective strengths to overcome individual limitations. Such solution should give the industry a better metrology solution than the conventional approach.

In this paper, we will present and discuss a new methodology of CD metrology so-called hybrid CD metrology that mixes CD data coming from different techniques (e.g CD-SEM and CD-AFM). The latest results obtained with the first hybrid universal engine will be presented. As a function of the model used in the methodology we will show and discuss the impact on CD RMS error versus the reference technique outputs. Finally, we will discuss the future orientations of hybrid metrology engine as a generic tool compatible with any kind of CD metrology techniques.

8378-16, Session 4

Deformation of polystyrene nanoparticles under different AFM tapping loads

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Atomic force microscopy (AFM) is a popular tool to measure the spherical nanoparticles adsorbed on a flat substrate, which is common in inspection of the surface properties of photocatalytic nanoproducts. The sizes of the nanoparticles using AFM probing can be decided by either height or the distance between neighboring particles. However, nanoparticle deformation can be a critical factor to contribute to the diameter uncertainty in the AFM measurements. In this work, the height measurements were performed to evaluate the deformation of the 100 nm polystyrene (PS) nanoparticles. The applied tapping loads ranged from 5 nN to 20 nN. The height measurements were repeated 10 times on the 7 randomly selected PS nanoparticles. The experimental results showed that the average size of nanoparticles decreased from 85.20 nm to 81.86 nm linearly after 10 repeated measurements. The estimated deformation by each AFM probing is ~0.33 nm, when the applied tapping load is 2.5 nN. Additionally, the heights of the PS nanoparticles were obtained from average of 10 measurements at 2.5 nN, 5 nN, 10 nN and 15 nN. It can be found that the heights of PS nanoparticles decreased with increasing applied tapping loads. The difference between 2.5 nN and 15 nN is up to 16.95 nm. Since severe deformation was observed for the applied tapping force of 15 nN, it is very difficult to obtain clear morphology of the PS nanoparticles measured at larger tapping loads (15 nN and 20 nN). Evidently, the applied tapping force significantly influence the AFM measurement of particle size. Therefore, it is necessary to characterize or control the tapping force in the AFM height measurements to increase the measurement accuracy.

8378-17, Session 4

Influence of surface coatings on nanoparticle measurement with atomic force microscopy

M. A. Lawn, A. K. Jämting, V. A. Coleman, H. J. Catchpoole, J. Herrmann, National Measurement Institute of Australia (Australia)

When imaging particles with atomic force microscopy (AFM), the measured apparent particle height depends on the interaction of the AFM tip with both the particle and the substrate which may be further influenced by surface coatings and adsorbed layers present on the various surfaces. During sample preparation for microscopy, the substrate and/or the particles may be coated with with suitable functionalising layers to improve immobilisation of the particles.

Here, we investigate how different surface coatings on substrates and on well-characterized nanoparticle materials influence the apparent particle heights measured with AFM. Identifying and quantifying these influences is a prerequisite for estimating corrections to the measured particle heights in order to compensate for variations in the tip-sample interactions associated with the presence of the surface coatings.

8378-18, Session 4

Extension of gravity center method for diameter calibration of polystyrene standard particles with a metrological AFM

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Polystyrene latex standard particle is one of the most important reference materials for calibration of inspection apparatus, for instance a particle counter. Recently, particle diameter calibration technology with a metrological atomic force microscope (AFM) has been developed by mainly national metrology institutes (Meli 2005, Garnaes 2011). In the particle diameter calibration with a metrological AFM, the distance between an apex of a particle and a substrate is defined as a vertical diameter. When closed packed structure of particles is obtained, the distance between center points of neighboring two particles is defined as a lateral diameter. In the previous studies, a line profile was manually extracted from a metrological AFM data. A pitch calculation method of one-dimensional grating was directly applied to the line profile and a lateral diameter was calculated. However, the way of extracting line profile is depending on individuals and there is a possibility of a bias in the calculated lateral diameter from person to person. We developed a diameter calibration technology of polystyrene particles with our metrological AFM. In this study, the center of gravity method was extended to three dimensions and the center point of gravity in each particle was calculated. The distance between center points of gravity of neighboring two particles was defined as a lateral diameter. The lateral diameter was calibrated and the uncertainty in lateral diameter calibration was evaluated. Furthermore, in the vertical diameter calibration, deformation of particles using Young's modulus of polystyrene thin film was calculated.

8378-19, Session 5

Modeling for multi-beam microscopy

D. C. Joy, The Univ. of Tennessee (United States); B. J. Griffin, The Univ. of Western Australia (Australia)

Scanning microscope images can only be properly interpreted if the details of the beam interaction with the sample are known. It is therefore necessary to know, for example, secondary and backscattered electron yields as a function of specimen chemistry and beam energy as well as the details of the interaction volume of the incident beam in the target. Regrettably, even after one hundred years of access to electrons, the data available is limited in quantity and dubious in quality.

In scanning ion microscopy the situation is worse because multiple ion beams may be available, and because the experimental data base is much more restricted. It will be demonstrated that by applying the IONiSE model of secondary electron production the ion induced secondary electron (iSE) yield can be predicted for any ion, beam energy, and angle of incidence, provided that the stopping power of the material of interest is known and that the relevant iSE yield excitation energy and diffusion length have previously been determined for the interaction of at least one ion beam in the material of interest. While no prediction can be a true substitute for a proper measurement this procedure provides useful data for initial studies and for modeling. Examples of data generated in this way will be provided.

8378-21, Session 5

The sensitivity of backscattering coefficients to elastic scattering cross sections and electron stopping powers

M. M. El-Gomati, The Univ. of York (United Kingdom)

The sensitivity of Monte Carlo estimates of backscattering coefficients η to the accuracy of their input data is examined by studying the percentage change in η due to changes of 10% and 20% in the differential elastic scattering cross section $d\sigma/d\Omega$ and corresponding changes in the stopping power S(E) in the primary energy range 200-10,000 eV. To a good approximation equivalent elastic and inelastic scattering changes produce equal and opposite shifts in η, a result consistent with predictions of transport theory. For medium to high atomic numbers an x% error in the specification of either S(E) or $d\sigma/d\Omega$ produces a percentage change in η significantly less than x%, while at low atomic number $\Delta\eta/\eta$ increases approximately linearly with lnE so that Monte Carlo predictions are then more sensitive to parameter precision at high energy.

8378-22, Session 5

Modeling and verification of SEM Imaging simulation of crystalline copper with amorphous top layer

S. Takada, State Univ. of New York (United States) and Hitachi High-Technologies Corp. (Japan); M. Suzuki, Hitachi High-Technologies Corp. (Japan); S. S. Borisov, Abeam Technologies (United States); E. Eisenbraun, The State Univ. of New York (United States)

According to shrinkage of semiconductor feature size, both of the performance and reliability of copper (Cu) interconnects are becoming challenging issues. The characteristics of Cu interconnects strongly depend on its crystalline structure, such as grain size, crystal orientation and grain boundary conditions. Backscattered electron (BSE) imaging by using scanning electron microscopy (SEM) would be a promising method to realize a quick characterization of metal films. A major drawback of SEM-based method, however, is a very small difference of signal intensity among different crystal orientations. Therefore, optimizing the SEM imaging conditions is truly essential to maximize the crystallographic contrast in SEM images.

The purpose of our study is to develop a crystallographic contrast simulating tool so that one can effectively optimize the imaging conditions. The simulating tool is developed based on a Monte-Carlo method, and is verified by using our systematic experiments. The newly-developed code is capable of treating electron channeling and blocking effects by the lattice planes. The code is implemented into a commercial Monte-Carlo platform, CHARIOT. In order to evaluate the accuracy of our simulation model, relative variation of BSE signal intensity (Delta n) among various crystal orientations is introduced. Delta n is calculated for various electron beam energies and various thickness of top layer above the Cu surface. As for the material of the top layer, we considered carbon as a contamination layer, and amorphous Cu as a disordered surface layer.

In the experiment, electro-plated Cu thin films were prepared on silicon wafers and inspected under SEM. The comparison between simulation and experiment shows that, the trend of Delta n obtained in the experiment indicates the existence of a disordered Cu layer of 1-5 nm in thickness. The cross-section imaging by using transmission electron microscope (TEM) is performed to verify this comparison.

8378-23, Session 5

Image processing with Maple for simplified analysis in scanning microscopy

A. Mesa, EAFIT Univ. (Colombia)

The images provided by a scanning microscopes show diffraction patterns product of the scanning mechanism. Those are complicated to analyze without computational help, I tried to find a simple way to make it easier, applying an automatic method. I have used some of the tools included in the image processing toolbox of Maple to analyze patterns which are commonly found in the images provided by the scanning microscopes, to make interpretation easier for the ones that want to analyze the image. I consider that, for how simple and opened it is, the method I developed may be useful for the people interested in the applications and further research related to analyzing scanning microscope images.

8378-24, Session 6

Nano-manipulation systems for scanning electron microscope

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Traditionally scanning electron microscopy (SEM) is often used as a scientific instrument for providing high magnification images and analytical capability for microstructural analysis. In recent decades different applications for SEM has been developed to focus characterizations of fine-scale materials such as in-situ annealing, cryo-microscopy, micro-tensile testing, electrical resistivity measurements and grain boundary/texture analysis (EBSD). With the increasing demand in these sub-micron to nano-scale characterizations, there's an increasing need to have a more sophisticated stage within the microscope. In other word, a stage that would have "hands" built onto the SEM stage to allow operator to manipulate objects and execute different tasks under high magnification. In this paper we presented a compact nanomanipulation system that is designed to be retrofitted easily onto many SEMs. Capabilites and potential applications such semiconductor electrical probing and insitu nanowire tensile testing using this manipulation system will be discussed.

8378-25, Session 6

Multi-signal FIB/SEM tomography

L. A. Giannuzzi, L.A. Giannuzzi & Associates LLC (United States)

Focused ion beam (FIB) milling coupled with scanning electron microscopy (SEM) on the same platform enables 3D microstructural analysis of structures using FIB for serial sectioning and SEM for imaging. Since FIB milling is a destructive technique, the acquisition of multiple signals from each slice is desirable. The feasibility of collecting both an inlens backscattered electron (BSE) signal and an inlens secondary electron (SE) signal simultaneously from a single scan of the electron beam from each FIB slice is demonstrated. Obtaining multiple signal types from each FIB slice within a single scan increases the acquisition throughput. In addition, optimization of microstructural and morphological information from the target is achieved using multi-signals. For example, material contrast is optimized using the BSE signal, thus, easily delineating the 3D morphology of multi-phase or multi-layered samples. The SE signal is particularly sensitive to topography or edge effects. On a smooth FIB slice, the edges of voids and porosity within a sample can be easily delineated using the SE signal. The simultaneous acquisition of two different SE signals from two different detectors (inlens vs. Everhart-Thornley detector) is also possible, unambiguously identifying internal voids or pores with a sample. Examples of multi-signal FIB/SEM tomography from a dental implant will be provided where both material contrast from the bone/ceramic coating/Ti substrate phases and

porosity in the ceramic coating will be characterized.

8378-26, Session 6

Automated multiple image acquisition for 3D tomography employing FIB-SEM

B. Van Leer, D. Wall, FEI Co. (United States)

While use of the electron beam in a DualBeam system is considered the primary imaging tool, ion beam induced secondary electron (SE) and ion (SI) images can provide high contrast, surface sensitive information not revealed with the electron beam. Factors that lead to ion beam contrast include ion channeling, passive voltage contrast, material differences and sensitivity to surface topography [1]. The use of a focused ion beam (FIB) to qualitatively understand grain orientation, grain boundary characteristics and other surface sensitive defects via FIB nanotomography with submicron precision has been shown on many systems including FeAl-based nanocomposites; the limitation with the technique was that the interspatial thickness resolution was approximately 100 nm [2]. This was overcome employing automated, drift-corrected serial sectioning and imaging with a scanning electron probe reducing the interspatial resolution to 15 nm [3]. Recent advancements in instrument automation have proven useful for serial sectioning using a focused ion beam and subsequent imaging by FIB microscopy or scanning electron microscopy (SEM). Other important three-dimensional techniques include TEM tomography and Atom Probe tomography. However, these techniques are sample preparation, data acquisition and analysis intensive. Furthermore, these techniques do not extend beyond feature sizes larger than 300 nm [4]. Automated serial sectioning with a FIB-SEM instrument provides a simpler method to achieve similar results for larger volumes, though the ultimate resolution is lower than these two methods. To optimize collection times and maintain high quality imaging results, FEI's Auto Slice and View G3 application software allows the user to optimize the FIB for high throughput serial sectioning. The application allows the user to acquire multiple images for each section that may consist of SEM induced SE or BSE images as well as FIB induced SE or SI images separately. A multilayer metal coating consisting of Ni and Sn on a Cu/Zn alloy specimen was studied to for delamination at the coating/substrate interface after fatigue to demonstrate the value of the application.

[1] Introduction to Focused Ion Beams, eds. L.A. Giannuzzi and F.A. Stevie, Springer (2005).

[2] B. J. Inkson et al., Scripta Mater., 45,753-8 (2001).

[3] L. Holzer et al., J. Am. Ceram. Soc., 89 [8] 2577-2585 (2006).

[4] B. J. Inkson et al., Scripta Mater., 45,753-8 (2001).

8378-27, Session 6

Nanostructuring of photonics devices in the helium ion microscope

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Helium ion microscopy (HIM) has been used both to create at to image nanostructures for photonic and plasmonic devices. Three different types of device fabrication tasks have been carried out. In each case the devices were created in thin metal films (100 nm or less) deposited onto optically transparent substrates. In each case, the helium ion beam is used to create the critical dimension light transmission features. The milled features display a machining precision of 5 nm (radius of curvature at corners). The same beam is used at a much lower dose to inspect the results. In one experiment, ion milling was utilized to create fractal "C-apertures" to amplify light intensity for high brightness photoemitters. Structures with lateral dimensions of 40 nm in a 90 nm thick Al film were produced and tested. Results of the characterizations, both of the geometry of the apertures and the light transmission, will be described. Second, the fabrication and inspection of Surface Enhance Raman Spectroscopy (SERS) structures will be presented. This will cover both the inspection of gold islands and the formation of small gaps (<10 nm) in gold "bowtie" structures. Finally, the milling of nanopore arrays for localized surface plasmon sensor studies have been carried out. The ion milling and characterization of these features will be described.

8378-28, Session 6

Advances in high-speed, low-latency communications for nanopositioning in advanced microscopy

S. C. Jordan, PI (Physik Instrumente) L.P. (United States)

We have entered an era in which new interfacing techniques are enablers, in their own right, for novel imaging techniques. For example, clever leveraging of new interfacing technologies has yielded nanoscale stabilization and resolution enhancement.

To assist in choosing and implementing interfacing approaches which maximize performance and enable new capabilities, we review available interfaces such as USB2, GPIB and Ethernet against the specific needs of positioning for the scanned-imaging community. We spotlight new developments such as LabVIEW FPGA, which allows non-specialists to quickly devise custom logic and interfaces of unprecedentedly high performance and parallelism. Notable applications are reviewed, including a clever amalgamation of AFM and optical tweezers, and a picometer-scale-accuracy interferometer devised for ultrafine positioning validation. We note the Serial Peripheral Interface (SPI), emerging as a high-speed/low-latency instrumentation interface. The utility of instrument-specific parallel (PIO) and TTL sync/trigger (DIO) interfaces is also discussed. Requirements of tracking and autofocus are reviewed against the time-critical needs of typical applications (to avoid, for example, photobleaching), as exemplified in recent capabilities for fast acquisition of focus with bumpless transition between optical and electronic position control. A novel planarization approach is reviewed, providing a nanoscale-accurate datum plane over large scan areas (up to 800x800um) without scan-line flattening. Finally, not to be overlooked is the original real-time interface: analog I/O, with novel capabilities introduced in recent months. Here additional advancements are discussed, including a resolution-enhancing technique for analog voltage generation and a useful combination of high-speed block-mode and single-point data acquisitions.

8378-29, Session 7

How much is enough? Spectrum depth and classification accuracy in automated particle analysis

J. Bharagava, Poolesville High School (United States); N. W. M. Ritchie, National Institute of Standards and Technology (United States)

Automated Particle Analysis by SEM/EDX (APA) is used extensively within the forensic community to identify characteristic particles and to characterize particulate samples. In part, the utility of the technique is based on the speed with which it can assign particles into distinct classes by composition. Some of the classes represent interesting types of particles, like the Pb-Ba-Sb particle type that is produced by many gun cartridge primers, others represent more mundane types like silicate minerals. To optimize the system throughput, the analyst will configure the automated system to collect the shortest duration spectrum which will produce reliable classification of interesting particles. Usually this optimization is performed in an ad hoc, trial-and-error manner. We would like to provide some useful insight and solid guidance in this process. We have performed studies on various particles of known composition in which we vary the acquisition duration to determine how acquisition time affects our ability to correctly classify the particles. Our studies show that even fairly low count spectra (~10,000 counts) can distinguish some challenging similar classes. Our studies also show that we must be careful about how we quantify the data. Careful consideration of limits of detection is critical as a sound appreciation of type I and II statistical errors.

8378-30, Session 7

Improving the performance of the critical dimension scanning electron microscope with the contrast transfer function

A. J. Cepler, SEMATECH (United States); B. Thiel, Univ. at Albany (United States)

Critical dimension scanning electron microscopes (CD-SEMs) are used extensively by the semiconductor industry to perform highly accurate dimensional metrology of patterned features. To ensure optimal feedback for process control, these tools must produce highly reproducible measurements. This means monitoring and minimizing not only day-to-day variations on a given tool, but also tool-to-tool variations whether within the same production facility or at different sites. It has been shown that the contrast transfer function (CTF) can be used to evaluate the imaging performance of SEMs [1] by giving a quantitative measure of the fidelity with which specimen contrast information (i.e., point-to-point variations in emitted signal intensity) is represented in the image data as a function of spatial frequency. Because all imaging defects and artifacts as well as the point spread function impact the shape of the CTF, it is an ideal means with which to monitor deviations from a baseline performance.

By using a thoughtfully designed and thoroughly characterized test specimen, the CTF of a given tool can be decoupled from the specimen information, allowing for characterization of the imaging system itself. Fresnel zone plates and pseudorandom arrays of dots are good candidates for such test structures, if they can be fabricated with sufficient resolution to assess the performance of the tool up to its information limit. The feasibility of this approach has been assessed with test structures fabricated using nano-imprint lithography with 22 nm design rules. The advantages of using the CTF of a specific instrument to improve CD-SEM image simulations are also demonstrated.

[1] Joy, D., Michael, J., and Griffin, J. “Evaluating SEM Performance from the Contrast Transfer Function,” Proc. Of SPIE, Vol 7638, 7638J-1 (2010).

8378-31, Session 7

How to get your SEM to always perform at its best

A. E. Vladár, P. Cizmar, M. T. Postek, National Institute of Standards and Technology (United States)

The scanning electron microscope (SEM) is used extensively in research, development and manufacturing. Today’s best instruments can achieve sub-nanometer spatial resolution at various landing energy (accelerating voltage), beam current and working distance settings. Their performance varies over time, and it is impossible to ensure its best without periodically monitoring it, and using the best practices to maintain it. Commonly, it might take several hours of effort to meet or exceed the specification for spatial resolution of images or other performance metrics. Over the past several years NIST has developed methods that could significantly improve this situation. These methods help to ensure that the SEM works closer to its optimal condition for all its applications.

There are several reasons for the degradation of the performance of the SEM. The focusing ability of the electron-optical column may become compromised. The cleanliness of the sample and the microscope is also very important. A carbonaceous contamination layer can be deposited and easily obscure the nanometer-scale, fine details of the sample, and lessens the secondary electron yield reducing the generated signal. Poor signal generation results in noisy images. In addition, mechanical vibration, electromagnetic fields, sample charging, and image acquisition limitations all must be minimized to be able to achieve and maintain the best instrument performance.

For almost all applications it is desirable to achieve the best possible performance. Optimal microscope performance and image acquisition parameters result in images that have more useful information than it otherwise would be possible. This talk will present methods that offer substantial improvements for current and future SEM imaging and measurements, which allow for the SEM to be used at its best performance.

8378-32, Session 7

An active pixel sensor for detecting low energy electrons

M. M. El-Gomati, The Univ. of York (United Kingdom); X. Zha, YPS Ltd. (United Kingdom)

A novel back-thinned complementary metal-oxide semiconductor (CMOS) active pixel sensor (APS) is reported for the direct detection of low energy electrons (500-2000 eV). The APS used contained 520 by 520 pixels of size 25 m2. It was installed in a JEOL 6400F scanning electron microscope (SEM) to determine its spatial resolution and detection response as a function of the incident electron energy. The obtained results show good linearity of the generated electron hole-pair signal as a function of the incident electron energy. The spatial resolution, measured as the full width at half maximum (FWHM,) is found to be of the order of 2 pixels. Examples of applying this sensor in a newly developed electron energy analyser are reported using the elastically scattered electrons of the SEM at various energies. The results obtained demonstrate the potential of using such a class of sensors in high vacuum environment, typical of SEMs.

8378-33, Session 7

Microanalysis of Al_2O_3-(Al-Fe) ceramic-metal interpenetrating phase composites using scanning and transmission microscopy techniques

V. C. Solomon, M. Moro, Youngstown State Univ. (United States); K. Peter, B. Hetzel, Fireline TCON, Inc. (United States); M. Zeller, T. R. Wagner, Youngstown State Univ. (United States)

Ceramic-metallic interpenetrating phase composites (IPC’s) produced by reactive metal penetration (RMP) have unique characteristics due to the fine intermixing of two or more phases with individual properties that are distinctly different from one another. Typical applications envisioned for IPC’s are high wear/corrosion resistant refractory materials for handling of molten materials, lightweight vehicle braking components, and high performance military body and vehicle armor. Preformed parts made of vitreous SiO2 were immersed in molten Al-7.5wt.%Fe alloy for several hours. During transformation, vitreous SiO2 reacts with the molten metal while the shape of the preform is preserved. Structural and chemical analysis of transformed material, using SEM/XEDS methods on metallographic and FIB-polished samples, demonstrates the coexistence of Al2O3 and Al interpenetrating phases, and indicates the presence of an Al-Fe phase. XRD investigation confirmed the presence of an Al-Fe phase but determination of the exact nature of the phase was difficult based on the X-ray diffraction pattern alone. Samples for S/TEM investigation were prepared using FIB methods. Through combining S/TEM imaging methods with XEDS and electron crystallography, two new metal phases were observed and investigated. Morphology, chemical composition and crystallographic structure of the micron-scale Al-Fe binary and nano-scale Al-Fe-Si ternary phases, will be reported.

8378-34, Session 7

Dispersion and alignment studies of electrospun CNT composites by focus ion beam

B. Berson, Jack M. Barrack Hebrew Academy (United States) and Univ. of Pennsylvania (United States); R. d. A. Cardona, J. J. Santiago-Aviles, E. M. Campo, Univ. of Pennsylvania (United States)

Electrospinning has seen a number of applications through the last decades. From the early adoption in the manufacturing of textiles, to the most recent applications in the life sciences as cell scaffolds, the utility of this versatile technique is still augmenting. Indeed, both mats of fibers and single fibers are protagonists in novel technological devices such as flexible electrodes or miniaturized high-performance sensors.

The advent of polymeric nanocomposites provides an added value to the already versatile electrospinning process. Indeed, the combined action of extrusion and electric forces are believed to induce an additional alignment in the fillers. Alignment of CNTs is a key parameter in the performance of composites, both in passive or active components, i.e. in structural or smart applications.

We have produced PDMS/PMMA fibers with dispersed MWCNTs by electrospinning. Initial SEM analysis suggests good dispersion and alignment of CNTs. Indeed, individual CNTs are observed to be aligned parallel to the fibers when those are near the surface. In addition, individual CNTs protrude from termination surfaces perpendicular to the fibers. However, surface SEM topography provides limited information on the overall distribution of the tubes throughout the fibers. This conjuncture is animating the study of filler alignment by focus ion beam. Despite the destructive character of this approach, a tomographic reconstruction of the volume will provide the veridic distribution of the fillers in the matrix.

8378-35, Session 8

Forensic practice in the field of protection of cultural heritage

M. Kotrly, I. Turkova, Institute of Criminalistics Prague (Czech Republic)

Microscopic methods play a key role in issues covering analysis of objects of art that are used on the one hand as screening ones, on the other hand they can lead to obtaining data relevant for completion of expertise. Analyses of objects of art, gemmological objects and other highly valuable commodities usually do not rank among routine ones, but every analysis is specific, be it e.g. material investigation of artworks, historical textile materials and other antiques (coins, etc.), identification of fragments (from transporters, storage place, etc.), period statues, sculptures with originals, analyses of gems and jewellery, etc.

A number of analytical techniques may be employed, such as - optical microscopy in transmitted and reflected light, polarization and fluorescence (visible, UV and IR); image analysis; quantitative microspectrophotometry; SEM/EDS/WDS; FTIR and Raman spectroscopy; XRF and microXRF, including mobile one; XRD and microXRD; x-ray transillumination; or LA-ICP-MS, SIMS, PIXE; further methods of organic analysis are also utilised - GS-MS, MALDI-TOF; etc.

The case of painting forgeries of a distinguished painter - Jan Zrzavý (30-ies) and a contemporary author Kristian Kodet can be presented as a practical example. 60 fake paintings of Jan Zrzavý and 12 forgeries of Kristian Kodet were investigated using comprehensive methods. In this case, microscopical and x-ray methods facilitated to distinguish forgeries. An interesting field represents examination of forgeries and altering of historical documents and chronicles with a view to gaining restitution claims and heirships, or authentication of blue blood to increase social status. In investigating these issues, besides the above-mentioned methods, our experts also apply methods of handwriting analysis.

8378-36, Session 8

Science and art at the nanoscale

B. A. Cola, Georgia Institute of Technology (United States); K. Voss, R. Gaither, Tucker High School (United States); J. Cola, Georgia Institute of Technology (United States)

The Georgia Institute of Technology NanoEngineered Systems and Transport (NEST) Lab in collaboration with the Georgia Tech Center for Education Integrating Science Mathematics and Computing (CEISMC) has been working with science and art teachers at Tucker High School in DeKalb County Georgia to establish a program that interfaces Nanoscience and Art education. The presentation will provide information about the ongoing program and how other schools could develop similar programs. The scope of the project is to use compost piles at the school to allow the environmental science students to explore energy generation in the compost and its possible conversion to electricity. Both the science and art classes are examining the composted material with optical and scanning electron microscopes to see the breakdown of materials at different scales. An SEM (Hitachi TM3000) is being used to allow the students to visualize and explore the nanostructure of materials that play a role in processes to convert heat energy to electricity. The art students will visually interpret the nanoscale images through various media. They will learn about ways to reduce our impact on the environment. The science students will monitor the compost pile's energy production but will also be introduced (by the art teacher) to the meanings of colors and color clichés and they will be asked to think about the color(s) of energy. They too will create visualizations from the SEM images. SEM images and art work will be shared with attendees.

8378-37, Session 8

The National Nanotechnology Infrastructure Network's Education and Outreach Programs: understanding size and scale and the tools of nano

N. Healy, Georgia Institute of Technology (United States)

Nanotechnology is considered by many to be the next "industrial revolution." The NSF estimates that by 2015 nanoscale science and engineering will be $3 trillion industry with the U.S. needing approximately 1 million workers. Workforce development programs are needed to excite students about possible education and career opportunities to ensure that the U.S. maintains its competitive edge in this fast-growing field. The National Nanotechnology Infrastruc¬ture Network (NNIN) is an integrated geographically-diverse partnership of 14 university-based laboratories supported by the National Science Foundation. The primary focus of NNIN is to serve as state-of-the-art resource centers for researchers. The NNIN also has extensive education outreach programs for the K-gray population.

The purpose of this presentation will be twofold: 1. provide an overview of the NNIN's education and outreach programs and 2. provide information on how we are teaching students about size and scale and the tools of nanotechnology, including scanning electron microscopy.

We have found that most students can provide the various SI units of measurement and may even define these prefixes. But where most students have difficulty, is understanding differences in size and scale as materials move from macro to micro to nano scales. This session will share lessons we use to help students understand concepts relating to size and scale because of their importance in eventually allowing students to understand nanoscale phenomena. The lessons will include how we incorporate microscopy into our outreach programs.

8378-38, Session 8

Integrating research and advanced microscopy into the high school curriculum

D. Becker, C. Queenan, A. Calabro, Bergen County Academies (United States)

The Bergen County Academies is a public magnet high school focused on science, technology, engineering and mathematics (STEM) education. One of the highlights of STEM education at the school is the integration of advanced microscopy into the curriculum and research programs. The school is home to the Nano-Structural Imaging Lab (NSIL) where students have access to a scanning electron microscope (SEM), a transmission electron microscope (TEM), and a laser scanning confocal microscope (LSCM).

Students at the Academies have the opportunity to conduct, present and defend scientific research using advanced scientific tools and techniques. There are three main methods for students to utilize the instrumentation available in the NSIL: enroll in the microscopy course; develop an independent research project; or participate in an interdisciplinary exercise combining microscopy and liberal arts.

Students enrolled in the elective Introduction to Microscopy learn the theory of and history behind basic light and fluorescence microscopy, SEM and TEM. Students receive hands-on training during small group lab exercises, allowing them to operate and image with each instrument. The lessons in the elective are correlated with New Jersey core curriculum content standards (CCCS) in science, technology, and English (for scientific writing).

Students involved in research have the unique opportunity to develop and carry out their own independent projects in areas such as nanotechnology, chemistry, biotechnology, molecular biology and genetics using professional level equipment specific to those disciplines. Students use the microscopes to image and characterize their samples, adding an increased layer of analysis. Students may also participate in collaborative research projects with outside institutions including local hospitals, corporations, universities and government research labs, affording them the opportunity to interact with industry and academic professionals and see real-world examples of microscopy in research.

Interdisciplinary exercises are meant to excite liberal arts students about STEM and microscopy. The joint microscopy-visual arts project involves graphic arts students collecting scientific data by imaging with the SEM. Students apply colorization and other artistic techniques to the images they acquire and present their work to peers. These cross-curriculum exercises assist in not only generating interest from students who normally would not come into contact with advanced microscopy, but also expands the curriculum connections for microscopy at the high school level.

Improving STEM education is critical for developing the next generation of American scientists, and microscopy is a tool that can be used to excite students about choosing a career in science.

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8378-39, Session 10

Synthesis of silicon nanowires via electron-beam templating and metal-assisted catalytic etching

D. Fleischman, K. F. Murphy, D. S. Gianola, Univ. of Pennsylvania (United States)

Quasi-1D silicon nanowires have been proposed as the building blocks for functional devices such as photovoltaics and thermoelectrics for use in energy conversion. Tailoring functionality can be accomplished via nanostructure size, shape, array, and doping control; however, current synthesis methods such as vapor-liquid-solid growth from metal catalysts show limitations in addressing all of these features. We have developed a method of fabricating silicon nanowires that has overcome these challenges, which relies on metal-assisted catalytic etching of a precisely defined template applied to commercially available silicon wafers. Electron beam lithography is used to describe the shape, size and periodicity of the resultant nanowire array by templating prior to the subsequent deposition of a metal catalyst layer. Etching of the wafer in an aqueous H2O2 and HF solution selectively attacks the silicon-metal interface in a manner that is independent of substrate orientation, allowing for a range of nanowire axial orientations. Nanowire cross-sectional shape and array geometries are easily defined by the electron-beam during templating with resolutions below 10 nm. We describe characterization of nanowire length, size, and feature definition as a function of fabrication parameters (e.g. lateral spacing of nanowires, metal-substrate adhesion) by employing electron microscopy. In addition, the mechanical properties of individual nanostructures produced from this process are characterized by tensile testing employing a microelectromechanical device and a custom-built in situ apparatus. Nanowire force and strain are measured via digital image correlation of image sequences obtained during mechanical testing.

8378-40, Session 10

Robust probes for high-resolution chemical detection and imaging

R. L. Agapov, The Univ. of Akron (United States); A. P. Sokolov, Oak Ridge National Lab. (United States) and The Univ. of Tennessee (United States); M. D. Foster, The Univ. of Akron (United States)

There are needs for both high resolution imaging and high sensitivity detection/analysis of surface chemistry on a nanometer scale. These needs can be addressed with Raman spectroscopy coupled with schemes that provide extraordinary enhancement of the Raman signal, namely surface enhanced (SERS) and tip enhanced (TERS) Raman spectroscopy. Advances in applications of high resolution imaging and high sensitivity detection will be enabled by two specific improvements: increased signal enhancement and increased robustness of the plasmonic structures needed to achieve enhancement. Robustness and stability are especially important for those plasmonic structures made of silver that usually provide the best enhancements. Here we focus particularly on TERS, in which a plasmonic structure is placed on a scanning probe microscope tip in order to achieve high lateral resolution imaging. We have demonstrated that aluminum oxide protected silver plasmonic structures show significantly increased robustness against chemical and mechanical degradation when compared to unprotected analogues without loss of enhancement. A 2-3 nm thick coating of aluminum oxide prevents chemical attack of the underlying silver film for three months in a desiccator, significantly increasing the storage life of current probes. The same protective coating also extends the scanning life of the probe two times (from 25 to 50 min) when the probe is used to image a hard patterned silicon substrate.

8378-41, Session 10

Relation between morphological and processing parameters in the electro-spinning of poly-lactic acid (PLA) - carbon nano-tubes (CNT) composites

E. M. Campo, Univ. of Pennsylvania (United States); M. Berrios-Soto, Univ. de Puerto Rico Mayagüez (United States); R. d. A. Cardona, J. J. Santiago-Aviles, Univ. of Pennsylvania (United States)

Carbon nano-tubes with their high electrical and thermal conductivity are often utilized as filler for polymer based composites in the field of batteries and super-capacitors. This abstract relates part of the characterization effort in understanding how to best “tune” a simple electro-spinning set-up so by selecting the filler (CNT) to binder (PLA) ratio, syringe pump speed, electrostatic potential (voltage) and distance from the syringe needle (high voltage) to substrate (ground potential) one can deposit fibers of the proper morphology including diameter distribution.

Composites varying the filler / binder ratio from 0.1 to 0.5 mg/mL were prepared. For the binder, a solvent consisting of 1:3 acetone / chloroform solvent was used. The spinning electrostatic potential was varied from 4-8 kV and the distance from anode to cathode was varied from 3-6 cm. For the syringe pump speed, the ranges from 5 to 0.5 mL/hr were examined.

Scanning Electron micrographs were obtained using a Focus Ion Beam FEI Strata -DB 235 on secondary electron mode to image uncoated fibers at room temperature. The resulting micrographs point to distribute morphologies, with apparently uniform filler distribution and in terms of morphology, cluster around well-discerned traits. These can be best described as three distinct groups from seemingly circular small cross sections, through ellipsoid cross sections and intermediate diameters to flat ribbon like cross sections, with the long axis several time its height.

8378-42, Session 10

Response of electrospun CNT composites to IR-irradiation

E. M. Campo, Univ. of Pennsylvania (United States); I. Ramos, S. Rosa, J. P. Crespo, Univ. de Puerto Rico en Humacao (United States); J. J. Santiago-Aviles, Univ. of Pennsylvania (United States)

Electrospinning of technology-relevant compounds could offer a simple bottom-up solution to integrate one-dimensional nanostructures in practical devices. In electrospinning, the reported ease of use, combined with the spatially controlled deposition of fibers in adequately patterned substrates could open unexplored avenues in micro and nano-systems technology manufacturing. In the context of nanocomposites, electrospun fibres appear to yield well-aligned CNTs; critical to the advent of these nanocomposites in practical applications. In fact, great effort is being dedicated to develop effective methods for dispersion and alignment of CNTs for which some researchers have proposed electrospinning and pyrolysis.

Polymer-CNT composites are known to have increased thermal, and mechanical properties. Contrary to their thin-film counterparts, little effort has been dedicated to examine the active behavior of electrospun polymer-CNT composites. We have studied the behavior of electrospun PDMS/PMMA-CNT composites under IR irradiation. In this scheme, dispersed MWCNTs were dissolved in a Poly(dmethylsilocaxe)/Poly(methylmethacrylate) precursor solution and electrospun nanofibers were collected on a 10 in x 10 in cardboard with two strips of aluminum foil to improve alignment. The nanofibres were irradiated with a visible light source of 40W and a deformation of approximately 1mm was observed.

8378-43, Session 10

Effects of impurities on stress-driven microstructural evolution in nanocrystalline aluminum

P. J. Malone, M. He, Univ. of Pennsylvania (United States); G. Feng, Villanova Univ. (United States); D. S. Gianola, Univ. of Pennsylvania (United States)

Understanding nanoscale deformation mechanisms is crucial to developing the next generation of advanced structural engineering materials for long-term reliability. Nanocrystalline metals and alloys, possessing grains with sizes less than 100 nm, have been reported to demonstrate high strengths and hardness. However, it has not yet been possible to tailor these materials for high toughness and stability against microstructural evolution. The presence of impurities, which are known to segregate to grain boundaries, greatly affects a material’s mechanical behavior. The material’s plastic response is especially affected, as these impurities act to pin stress-driven microstructural evolution. Nanocrystalline films have shown a crossover from strong, brittle behavior at high impurity concentrations, to less stiff, more ductile behavior in “cleaner” samples. However, the critical concentration required for stability against stress has not been elucidated systematically. To address this, thin films of aluminum containing varying amounts of oxygen impurities have been co-sputtered from aluminum (99.999%) and aluminum oxide (99.995%) targets, with the goal of developing a combinatorial synthesis technique to study the effects of impurity concentration on mechanical behavior in nanocrystalline materials. RBS is used to determine global film composition, and SEM-EDS for compositional mapping. Film microstructure is studied in TEM, and information about the grain size distribution as well as the local composition at the grain boundaries is extracted. Additional information about local structure at the grain boundary is obtained by 3-dimensional atom probe (3DAP) tomography. Finally, mechanical properties are obtained for a variety of compositions and microstructures using nanoindentation and are correlated with microstructural stability.

Conference 8379: Laser Radar Technology and Applications XVII

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8379-01, Session 1

Three-dimensional imaging with 1.06um Geiger-mode ladar camera

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Three-dimensional (3D) topographic imaging using Short wavelength infrared (SWIR) Laser Detection and Range (LADAR) systems have been successfully demonstrated on various platforms. LADAR imaging provides coverage down to inch-level fidelity and allows for effective wide-area terrain mapping. Recently Spectrolab has demonstrated a compact 32x32 LADAR camera with single photo-level sensitivity with small size, weight, and power (SWAP) budget. This camera has many special features such as non-uniform bias correction, variable range gate width from 2 microseconds to 6 microseconds, windowing for smaller arrays, and short pixel protection. Boeing integrated this camera with a 1.06 m pulse laser on various platforms and had demonstrated 3D imaging. In this presentation, the operation details of this camera and 3D imaging demonstration using this camera on various platforms will be presented.

8379-02, Session 1

Low-cost compact MEMS-scanned ladar system for robotic applications

R. D. Moss, P. Yuan, X. Bai, R. Sudharsanan, E. Quesada, Spectrolab, Inc. (United States); B. L. Stann, J. F. Dammann, M. M. Giza, W. B. Lawler, U.S. Army Research Lab. (United States)

Future robots and autonomous vehicles require compact low-cost Laser Detection and Ranging (LADAR) systems for autonomous navigation. Army Research Laboratory (ARL) recently demonstrated a brass-board short-range and eye-safe MEMS-scanned LADAR system for robotic applications. Boeing Spectrolab is doing a tech-transfer of this system and is building a commercial version that is compact and rugged and with additional improvements in receiver sensitivity, laser system, and data processing.

Improved system sensitivity, low-cost, miniaturization and low power consumption are the main goals for commercialization of this LADAR system. The receiver sensitivity has been improved by 2x using large-area InGaAs PIN detectors with low-noise amplifiers. The signal processing code has been updated to extend the range to 50 meters and detect up to 3 targets per pixel. Range accuracy has been improved through the implementation of an optical T-Zero input line. A compact commercially available erbium fiber laser operating at 1550 nm wavelength is used as a transmitter thus reducing the size of the LADAR system considerably from the ARL brass-board system. The computer interface has been consolidated to allow image data and configuration data (configuration settings and system status) to pass through a single Ethernet port. In this presentation we will discuss the system architecture and future improvements to receiver sensitivity using avalanche photodiodes.

8379-03, Session 1

Pulsed 3D laser sensor with scan-less receiver

H. Tsuji, A. Hirai, N. Kotake, M. Imaki, S. Kameyama, M. Takabayashi, Y. Hirano, Mitsubishi Electric Corp. (Japan)

3D laser sensor is the real-time remote sensor which offers 3D images of the scene. Since this sensor has the potential to get an image of a fast moving target, this is attractive for many applications including robotics, terrain visualization, augmented vision, reconnaissance, and so on.

In the previous study, we have introduced the concept of the real-time 3D laser sensor with 1D line scan of transmitted beam and scan-less receiver. In this paper, we demonstrate new concept of the real-time 3D laser sensor with 2D scan of transmitted beam and scan-less receiver.

We introduce developed key devices which are high-aspect APD array and receiver IC, and prototype of the system. With the prototype, we realize a 160 × 120 pixels real-time range imaging at a distance of more than 100 m.

8379-04, Session 1

Flash lidar performance testing: configuration and results

I. Poberezhskiy, A. Johnson, D. Chang, E. Ek, D. Natzic, G. Spiers, Jet Propulsion Lab. (United States); S. Penniman, B. Short, Advanced Scientific Concepts, Inc. (United States)

Future planetary and lunar landers would benefit from a Hazard Detection (HD) system that employs a lidar to create a high-resolution 3D terrain map in the vicinity of the landing site, along with an onboard computer to process the lidar data and identify the safest landing spot within the surveyed area. A divert maneuver would then be executed to land in this safe spot. Such a HD system will enable landing in regions with relatively high hazard abundance that would otherwise be considered unacceptably risky, but are often of particularly high interest to the scientific community.

One key component of a HD system is a lidar with the ability to generate a 3D terrain image with the required precision and accuracy in the prescribed time, that fits within the resource constraints defined by the project. In principle, both flash and scanning lidars can be viable for HD.

In this paper, we will present the results obtained during performance testing of the prototype “GoldenEye” 3D flash lidar developed by Advanced Scientific Concepts, Inc for eventual space deployment. This lidar employs a 128x128 pixel detector array and passively Q-switched Nd:YAG laser. Laser diffuser and receiver optics are swappable to change the field of view. The testing was performed at the JPL Mesa facility with the lidar and the targets separated by 200m. The targets were flat boards of varying albedo and hemispheres of different radii attached to these boards. The analysis of 3D data obtained for different targets, FOVs, and incidence angles will be presented, including per-pixel range noise, patch range noise, and intensity-dependent noise performance.

8379-06, Session 2

Detecting trails in lidar point cloud data

A. M. Kim, R. C. Olsen, Naval Postgraduate School (United States)

Methods exist for identifying trails in LiDAR data which are successful under limited and specific conditions. The goal of this work is to determine methods which are robust under diverse conditions, and which fully exploit the 3-dimensional nature of LiDAR data. Exploiting raw point cloud data enables high accuracy to be achieved, but the irregularly-gridded nature of the data means it is difficult to efficiently process. Interpolated data products, such as Digital Elevation Models (DEMs), can be easily viewed and processed in a wide variety of software packages; however, there is an inherent loss of accuracy and introduction of error when the data is interpolated. The interpolation process requires assumptions be made about the density of the data points, the curvature of the ground, and other factors which can lead to very different results in the final interpolated product. The approach presented in this work uses a combination of point-cloud filtering algorithms applied to the raw LiDAR point cloud data and line/curve detection algorithms applied to interpolated data products. This combined approach maximizes the advantages of both the raw data and the interpolated data products. Initial results will be presented.

8379-07, Session 3

Line-of-sight measurement in large urban areas using voxelized lidar

S. Hagstrom, D. Messinger, Rochester Institute of Technology (United States)

Recent advances in LIDAR technologies have increased the resolution of airborne instruments to the sub-meter level, which opens up the possibility of creating detailed maps over a large area. The ability to map complex 3D structure is especially challenging in urban environments, where both natural and manmade obstructions make comprehensive mapping difficult. LIDAR remains unsurpassed in its capability to capture fine geometric details in this type of environment, making it the ideal choice for many purposes. One important application of urban remote sensing is the creation of line of sight maps, or viewsheds, which determine the visibility of areas from a given point within a scene. Using a voxelized approach to LIDAR processing allows us to retain detail in overlapping structures, and we show how this provides a better framework for handling line of sight calculations than existing approaches. Including additional information about the instrument position during the data collection allows us to identify any scene areas which are poorly sampled, and to determine any detrimental effect on line of sight maps. An experiment conducted during the summer of 2011 collected both visible imagery and LIDAR at multiple returns per square meter of the downtown region of Rochester, NY. We demonstrate our voxelized technique on this large real-world dataset, and derive where errors in line of sight mapping are likely to occur.

8379-08, Session 3

Real-time 3D change detection of IEDs

M. Wathen, U.S. Army Research Lab. (United States); N. Link, CAE (Canada); P. Iles, Neptec Design Group Ltd. (Canada); P. Mrstik, GeoDigital International Inc. (Canada); J. Jinkerson, CAE USA (United States); D. Kovats, CAE (Canada); K. Kusevic, GeoDigital International Inc. (Canada)

Road-side bombs are a real and continuing threat to soldiers in theater. The Army Research Labs (ARL) has recently contracted with CAE USA for the prototype development of the Volume-based Intelligence Surveillance Reconnaissance (VISR) sensor platform. This vehicle-mounted, prototype sensor system uses a high data rate LiDAR (1.33 million range measurements per sec) to generate a 3D mapping of roadways. The mapped data is used as a reference to generate real-time change detection on future trips on the same roadways. The prototype VISR system is briefly described.

The focus of this paper is the methodology used to process the 3D LiDAR data, in real-time, to detect small changes on and near the roadway ahead of a vehicle traveling at moderate speeds with sufficient warning to safely stop the vehicle. The system relies on accurate navigation equipment to geo-reference the reference run and the change detection run. It was recognized early in the project that detection of small changes could not be achieved with accurate navigation solutions alone. A scene alignment algorithm was therefore developed to register the reference run with the change detection run prior to applying the change detection algorithm. Good success was achieved in simultaneous real-time processing of scene alignment plus change detection.
The paper concludes with suggestions of future enhancements to performance and additional features.

8379-09, Session 3

A new method of 3D reconstruction using point cloud and distance images of laser radar

J. Lan, J. Li, Univ. of Science and Technology Beijing (China)

Laser Scanning is one of the 3D scanning techniques,we can get the 3D coordinates of the object's surface by using the ladar to scan.Compared with the traditional measuring methods,laser scanning technology can achieve the measurement of the points,lines and surface of the complex structures.It can do the measurement in none-contact way,which is fast in speed and high in accuracy.It plays an important role in the reconstruction in many fields by using the 3D scanning data.

As for the characteristic of the data acquired by laser radar and the three dimentional point cloud in disorder, and by combining the abundant in three dimentional information of point cloud with the specific textural information of distance images,we raised a new algorithm on the reconstruction of laser radar based on simplified point cloud and distance images.In this article,we take advantage of the feature that Delaunay triangulation have to raise a simplified algorithm to achieve the model network.In this algorithm,at first we build up the Delaunay triangulation,then comfirm the vector by calculating the distance that every vertex in the network from the adjacency vertex,and then calculate the intersection angle that the vector with triangle around;at the same time set the angular threshold in order to generate the new Delaunay triangulation.Experimental results show that this algorithm can accomplish the simplication of triangulation without affecting the accuracy of the modeling,along with the detailed,textural and shading information,we can achieve 3D reconstruction of the target images effectively.

8379-10, Session 3

Landing zone determination using video rate point cloud data

C. T. Rodgers, J. Méndez-Rodríguez, ITT Corp. Geospatial Systems (United States)

Previous efforts to classify safe landing zones based on 2D and 3D imagery is still in its infancy. 2D imagery can be processed in real time, but do not offer the required information to determine factors such as slope, roughness, and height within the scene. 3D imagery, such as digital terrain elevation data (DTED) and LIDAR point cloud datasets, offer either course estimates (DTED) or finer detail of the height information (LIDAR) in the scene. This height information can offer initial information to identify prospective landing zones. However, these 3D datasets do not offer information in real time based on how the scene height information has changed with respect to when the data was acquired. As such, there is a need to process 3D information in real time for the required situational awareness in landing zone applications. In this work, we describe an algorithm that provides near real time processing of video rate point cloud datasets to determine safe landing zones. We provide example datasets that are both video rate and single frame datasets to demonstrate the algorithm's timely results.

8379-11, Session 3

Foliage penetration by using 4D point cloud data

J. Méndez-Rodríguez, P. J. Sánchez-Reyes, S. M. Cruz-Rivera, ITT Corp. Geospatial Systems (United States)

Real time awareness and rapid target detection are critical requirements for military missions. Obscured targets under forest areas can be detected and tracked by using airborne LAser Detection And Ranging (LADAR) systems. LADAR systems are very popular to generate high resolution maps in the 3D space. Now, a new technology is under development to generate 4D datasets (3D video in a point cloud format) and the implementation of algorithm able to process the data in real time is needed. Our publication will present an algorithm capable to detect targets in forest areas by removing the vegetation in a real time 3D environment. A real time 3D awareness system can help pilots to be aware of high risk targets (i.e. tanks, cannons, etc.). We will be using a 4D simulated point cloud data to demonstrate the capabilities of our algorithm.

8379-12, Session 3

Geometric-model-free tracking of extended targets using 3D lidar measurements

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Tracking of extended targets in high definition 360 degree 3D-LIDAR (Light Detection and Ranging) measurements is a challenging task and a current research topic. It is a key component in robotic applications, and is relevant to path planning and collision avoidance.

This paper proposes a new method without a geometric model to track and accumulate 3D-LIDAR measurements of an object simultaneously. The method itself is based on a particle filter and uses an object-related local 3D grid for each object. No geometric object hypothesis is needed. Accumulation allows coping with occlusions.

The prediction step of the particle filter is governed by a motion model consisting of a deterministic and a probabilistic part. Since the paper is focused on tracking ground vehicles, a bicycle model is used for the deterministic part. The probabilistic part depends on the current state of each particle. A function for calculating the current probability density function for state transition is developed. It is derived in detail and based on a database consisting of vehicle dynamics measurements over several hundreds of kilometers. The adaptive probability density function narrows down the gating area for measurement data association.

The second part of the proposed method addresses the weighting of the particles with a quality function. Different quality functions depending on the 3D grid are presented and evaluated.

Evaluations with real 3D-LIDAR measurements show the performance of the proposed method. The results are also compared to ground truth data.

8379-13, Session 3

Improved target detection using occupancy grids

G. Tolt, T. R. Chevalier, P. Engström, C. A. Grönwall, Swedish Defence Research Agency (Sweden)

The new generation laser-based FLASH 3D imaging sensors enables collection of range images at video rate, at the ex-pense of somewhat low spatial and range resolution. Instead of analyzing each image separately, registering several suc-cessive range images can improve performance of feature extraction and target classification. In the robotics community occupancy grids, e.g. Octomaps, are commonly used as a framework for combining sensor readings into a representation that indicates passable (free) and non-passable (occupied) parts of the environment. In this paper we apply 3D occupancy grids to registration and target classification tasks. We show how the performance can be enhanced further by including laser system specific properties in the occupancy grid update policy. We illustrate how range data enables target classifi-cation in near real-time and that the results can be improved if several frames are co-registered. Different 3D registration techniques are compared and discussed and examples using data from forest and maritime scenes are shown.

8379-14, Session 3

A ladar bare earth extraction technique for diverse topography and complex scenes

A. L. Neuenschwander, T. H. Stevenson, L. A. Magruder, The Univ. of Texas at Austin (United States)

Bare earth extraction is an important component to LADAR data analysis in terms of terrain classification. The challenge in providing accuracy digital models is augmented when there is diverse topography within the data set or complex combinations of vegetation and built structures. A successful approach provides a flexible methodology (adaptable for topography and/or environment) that is capable of integrating multiple ladar point cloud data attributes. A newly developed approach uses a 2nd and 3rd order spatial derivative for each point in the DEM to determine sets of contiguous regions of similar elevation. Specifically, the derivative of the central point represents the curvature of the terrain at that position. Contiguous sets of high (positive or negative) values define sharp edges such as building edges or cliffs. This method is independent of the slope, such that very steep, but continuous topography still have relatively low curvature values and are preserved in the terrain classification. Next, a recursive segmentation method identifies unique features of homogeneity on the surface separated by areas of high curvature. An iterative selection process is used to eliminate regions containing buildings or vegetation from the terrain surface. This technique was tested on a variety of existing LADAR surveys, each with varying levels of topographic complexity. The results shown here include developed and forested regions in the Dominican Republic.

8379-15, Session 4

Ladar imaging analytical approach using both outward and return path atmospheric turbulence phase-screens

D. G. Youmans, Cobham Analytic Solutions (United States)

Laser radar imaging through atmospheric turbulence may be studied using laser-mode propagation through the outward atmospheric path which is conventionally modeled by using multiple turbulence phase-screens. Simultaneously, or near simultaneously, the return path turbulence effects may be modeled by a reverse order Cn2(h), Lo, lo set of phase-screens and assuming a plane wave. This return path amplitude & phase screen can be used to create an atmospheric impulse-response which is used to accurately construct the image of a diffuse target in the detector focal plane array. Agreement of both the outward and the return path phase-screen sets with analytical turbulence parameters (independently computed) will be shown. The target image construction process will be reviewed, employing conventional Fourier optics analysis, and typical diffuse target images of facet model objects will be presented illustrating scintillation and speckle effects. Comparison with various data collections will be given.

8379-16, Session 4

AGLITE: multiwavelength lidar for real-time characterization of aerosol mass concentration

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AGLITE is a multiwavelength lidar developed for quantitative measurement of particle emissions from animal production facilities. The lidar transmission system is a pulsed Nd:YAG laser (355, 532, 1064 nm) operating at a pulse rate of 10 kHz. We analyze and model lidar backscatter and extinction coefficients to extract aerosol physical

properties. All wavelength channels operate simultaneously, day or night, using photon counting and high speed data acquisition. The lidar housing is a transportable trailer suitable for all-weather operation at any accessible site. We direct the laser and telescope field of views to targets of interest in both azimuth and elevation. Arrays of particle samplers and turbulence detectors were also used by colleagues specializing in those fields and are compared with the lidar data. The value of multiwavelength, eyesafe lidars for agricultural aerosol measurements has been confirmed by the successful operation of AGLITE. In this paper, we demonstrate the ability of the lidar system to quantitatively characterize particulate emissions as mass concentration fields applicable for homeland security, troop protection and environmental applications. The combination of lidar with point characterization information allows the development of 3-D distributions of standard USEPA PM1o and PM2.5 mass concentration fractions. We demonstrate the ability to use “standoff” lidar methods to determine the movement and concentrations of emissions over an entire agricultural facility.

8379-17, Session 4

Ground and airborne methane measurements with optical parametric amplifier

K. Numata, H. Riris, S. Li, S. Wu, S. R. Kawa, M. W. Dawsey, A. Ramanathan, J. B. Abshire, NASA Goddard Space Flight Ctr. (United States)

We report on ground and airborne methane measurements with a differential absorption lidar using widely-tunable optical parametric amplifier (OPA). The technique has been used to measure methane (CH4), carbon dioxide (CO2), water vapor, and other trace gases in the near and mid-infrared spectral regions. Methane is a strong greenhouse gas on Earth and it is also a potential biogenic marker on Mars and other planetary bodies. A remote sensing instrument that can measure day and night over all seasons and latitudes can localize sources of methane and aid in the identification of global carbon cycle, oil fields, and volcanic activities. We have developed a nanosecond-pulsed OPA for remote measurements of methane. The OPA is pumped by a passive Q-switch NPRO (non-planar ring oscillator) at 1064nm and seeded by a continuous-wave DFB laser at 1550-1650nm. A 50-mm, MgO-doped PPLN was used as a nonlinear crystal. The OPA output light is single frequency with high spectral purity and is widely tunable both at 1600nm and 3300nm with an optical-optical conversion efficiency of ~40%. We have demonstrated detection of methane at 3.3 μm and 1.65 μm in horizontal open paths with 400 m and 3 km roundtrip lengths, respectively. We also report on preliminary airborne demonstration of methane measurements at

1.65 μm from ~10-km altitude.

8379-18, Session 4

Measurement of atmospheric formaldehyde profiles with a laser-induced formaldehyde lidar

G. Li, MassTech Inc. (United States); J. Lei, C. R. Prasad, Science & Engineering Services, Inc. (United States)

Formaldehyde is a trace species that plays a key role in atmospheric chemistry. It is an important indicator of non-methane volatile organic compound emissions. Also, it is a key reactive intermediate formed during the photochemical oxidation in the troposphere. Because the lifetime of formaldehyde in the atmosphere is fairly short (several hours), its presence signals hydrocarbon emission areas. The importance of measuring formaldehyde concentrations has been recognized by the National Academy’s Decadal Survey and two of NASA’s forthcoming missions the GEO-CAPE and GACM target its measurement.

There are several techniques some of which are highly sensitive (detection limit ~ 50 parts-per-trillion) for in-situ measurement of formaldehyde and many reported atmospheric measurements. However there appear to be no reported standoff lidar techniques for range resolved measurements of atmospheric formaldehyde profiles. In this paper, we describe a formaldehyde lidar profiler based on differential laser induced fluorescence technique. The UV absorption band in the 352 - 357nm is well suited for laser excitation with frequency tripled Neodymium lasers and measuring the strong fluorescence in the 390 - 500nm region. Preliminary nighttime measurements of formaldehyde were demonstrated with a lidar using a commercial Nd:YAG laser (354.7 nm) with a rather large linewidth (~.02 nm). The measured sensitivity was ~1 ppb at 1 km with 100 meters range resolution even with this non-optimized system. In this paper we describe our approach for increasing the sensitivity by many orders and for daytime operation by improving the laser parameters (power and linewidth) and optimizing the receiver.

8379-19, Session 4

Time-resolved remote Raman and fluorescence spectrometers for planetary exploration

S. K. Sharma, A. K. Misra, T. E. Acosta, P. G. Lucey, Univ. of Hawai’i (United States)

At the University of Hawaii, we have developed compact time-resolved Raman, and fluorescence spectrometers suitable for planetary exploration under NASA’s Mars Instrument Development Program. The compact Raman and fluorescence spectrometers consist of custom miniature spectrographs based on volume holographic gratings, and custom miniature intensified CCD cameras. These spectrographs have been interfaced with a regular 50 mm camera lens as well as with a three and a half inch diameter telescope for remotely interrogating minerals, glasses, bio-minerals and samples of interest for astrobiology. Using a small frequency-doubled Nd:YAG pulsed laser (35 mJ/pulse, 20 Hz) and 50 mm camera lens, Raman spectra of minerals, glasses and bio-minerals to 50 m distance can be measured within 30 s, and with 3.5-inch telescope these samples can be interrogated to 100 m radial distance during day time and nighttime. The fluorescence spectrograph is capable of measuring time-resolved laser-induced fluorescence in the spectral range 400-800 nm spectral range, and can assist in differentiating between abiogenic minerals from organic and biogenic materials based on the fluorescence lifetime. For a number of inorganic, organic and biological samples, Raman fingerprints have been clearly observed and correlated with the previous laboratory data. Biological materials are also identified from their characteristic short-lived (<10 nano s) laser-induced fluorescence lifetime. These instrument will play important role in planetary exploration especially in NASA’s future sample return, and lander and rover missions.

8379-20, Session 4

Simulation framework to estimate the performance of CO2 and O2 sensing from space and airborne platforms for the proposed ASCENDS mission implementation

D. V. Pliutau, N. S. Prasad, NASA Langley Research Ctr. (United States)

The Active Sensing of CO2 Emissions over Nights Days and Seasons (ASCENDS) mission recommended by the NRC Decadal Survey has a desired accuracy of 0.5% or better in carbon dioxide mixing ratio (XCO2) retrievals requiring careful selection and optimization of the instrument parameters. NASA LaRC is investigating 1.57 micron carbon dioxide as well as the 1.26-1.27 micron oxygen bands for our proposed ASCENDS mission implementation. Simulation studies are underway for these bands to select optimum instrument parameters. The simulations are based on a multi-wavelength lidar modeling framework being developed at NASA Langley to predict the performance of CO2 and O2 sensing

from space and airborne platforms. The modeling framework consists of a lidar simulation module and a line-by-line calculation component with interchangeable lineshape routines to test the performance of alternative lineshape models in the simulations. As an option the LBLRTM program may also be used for line-by-line calculations. The modeling framework is being used to perform error analysis, establish optimum measurement wavelengths as well as to identify the best lineshape models to be used in CO2 and O2 retrievals. Several additional programs for HITRAN database managements and related simulations are planned to be included in the framework. The description of the modeling framework with selected results of the simulation studies for CO2 and O2 sensing will be presented.

8379-21, Session 4

Airborne Doppler wind lidar data fusion with a diagnostic wind model

Y. Wang, U.S. Army Research Lab. (United States)

An initialization method using airborne Doppler wind lidar data was developed and evaluated for a massconsistent diagnostic wind model over complex terrain. The wind profiles were retrieved from the airborne lidar using a conical scanning scheme and a signal processing algorithm specifically designed for the airborne lidar system. An objective data analysis method in complex terrain was then applied to those wind profiles to produce a three-dimensional wind field for model initialization. The model results using the lidar data initialization were compared with independent surface weather observational data and profiles from a microwave radar wind profiler. The model was previously run for a small domain with simple terrain where comparisons with a surface observation array showed that the model performed well in a strong wind condition. For the more complex terrain in the Salinas valley, the model evaluation with a limited number of observations indicated that the diagnostic wind model with airborne Doppler lidar data also produced a reasonably good wind field in moderate to strong wind conditions. However, caution must be stressed for weak wind conditions in which the flow is thermally driven as the mass-consistent diagnostic wind model is not equipped to handle such cases. The effect of the lidar wind profile density over a simulation domain was also investigated for practical applications. The results indicate that about a half dozen lidar wind profiles would be adequate for a 20 by 20 km complex terrain domain with fairly uniform and moderate wind conditions.

8379-22, Session 4

Airborne wind profiling with the data acquisition and processing system for a pulsed 2-micron coherent doppler lidar system

J. Y. Beyon, NASA Langley Research Ctr. (United States)

A pulsed 2-micron coherent Doppler lidar system at NASA Langley Research Center in Virginia flew on the NASA's DC-8 aircraft during the NASA Genesis and Rapid Intensification Processes (GRIP) during the summer of 2010. The participation was part of the project Doppler Aerosol Wind Lidar (DAWN) Air. Selected results of airborne wind profiling are presented and compared with the dropsonde data for verification purposes. Panoramic presentations of different wind parameters over a nominal observation time span are also presented for selected GRIP data sets. The real-time data acquisition and analysis software that was employed during the GRIP campaign is introduced with its unique features.

8379-23, Session 4

Noise whitening in airborne wind profiling with a pulsed 2-micron coherent Doppler lidar at NASA Langley Research Center

J. Y. Beyon, NASA Langley Research Ctr. (United States)

Two different noise whitening methods in airborne wind profiling with a pulsed 2-micron coherent Doppler liar system at NASA Langley Research Center in Virginia are presented. In order to provide accurate wind parameter estimates from the airborne lidar data acquired during the NASA Genesis and Rapid Intensification Processes (GRIP) campaign in 2010, the adverse effects of background instrument noise must be compensated properly in the early stage of data processing. The results of the two methods are presented using selected GRIP data and compared with the dropsonde data for verification purposes.

8379-24, Session 5

Ladar performance simulations with a high spectral resolution atmospheric transmittance and radiance model: LEEDR

B. D. Roth, S. T. Fiorino, Air Force Institute of Technology (United States)

In this study of atmospheric effects on laser ranging and detection (LADAR or laser radar), the parameter space is explored primarily using the Air Force Institute of Technology Center for Directed Energy's (AFIT/CDE) Laser Environmental Effects Definition and Reference (LEEDR) code. The LEEDR model is a fast-calculating, first principles, worldwide surface to 100 km, atmospheric propagation and characterization package. In general, LEEDR defines the well-mixed atmospheric boundary layer with a worldwide, probabilistic surface climatology based on season and time of day, and then computes the radiative transfer and propagation effects from the vertical profile of meteorological variables. The expected performance of LADAR systems is assessed at operationally representative wavelengths of 1.064, 1.557 and 2.039 µm at a number of widely dispersed locations worldwide. Signal attenuation and background noise are characterized using LEEDR. These results are compared to standard atmosphere characterizations and assessments done with FASCODE. Scenarios evaluated are based on air to ground engagements including both down looking oblique and vertical geometries in which anticipated clear air aerosols and hydrometers are expected to occur. Seasonal and boundary layer variations are considered to determine optimum employment techniques to exploit or defeat the environmental conditions. Each atmospheric particulate/obscurant/hydrometeor is evaluated based on its wavelength-dependent forward and off-axis scattering characteristics and absorption effects on system interrogation. Results are presented primarily in the form of worldwide plots of notional signal to noise ratio. Signal to noise ratios are also coupled with extinction and blurring effects that impact tracking and imaging with LADAR.

8379-25, Session 5

Spatial integration considerations for coherent array receivers

P. Gatt, D. Jacob, Lockheed Martin Coherent Technologies (United States)

In this paper we present theoretical expressions for the CNR, resolution and image SNR of coherent array imaging receivers. In coherent array imaging (e.g., digital holography or spatial heterodyne imaging) the received signal's complex amplitude is spatially integrated (low pass filtered) by each receiver detector element forming a complex image in the image plane. To increase the CNR, over that afforded by the energy received in an individual detector element, the image's complex

amplitude is spatially integrated to reduce the out of band receiver noise. This integration generally takes place in post processing and, as such, one is free to choose any geometry for the integrator. For an adequately sampled complex image, one can increase the CNR by integrating over a greater number of detector elements. However, as the integration area begins to exceed the coherence area the integration efficiency and image resolution begin to degrade. We show that the optimal integrator providing the best trade of CNR and image resolution is simply the Fourier transform of the receiver pupil function.

Image SNR characterizes the fluctuation of the image irradiance about its mean and can be improved with additional post processing. Incoherently integrating the image irradiance either spatially or temporally beats down speckle and receiver noise and increases image SNR. We show that any increase in image SNR must result in a corresponding decrease in the spatial or temporal image resolution.

8379-26, Session 6

Noise filter techniques for photon-counting ladar data

L. A. Magruder, K. D. Stout, M. E. Wharton, A. L. Neuenschwander, The Univ. of Texas at Austin (United States)

Many of the recent small, low power ladar systems provide detection sensitivities on the photon(s) level for altimetry applications. These “photon-counting” instruments, many times, are the operational solution to high altitude or space based platforms where low signal strength and size limitations must be accommodated. Despite the many existing algorithms for ladar data product generation, there remains a void in techniques available for handling the increased noise level in the photon-counting measurements as the larger analog systems do not exhibit such low SNR. Solar background noise poses a significant challenge to accurately extract surface features from the data. Thus, filtering is required prior to implementation of other post-processing efforts. This paper presents several methodologies for noise filtering photon-counting data. Techniques include modified Canny Edge Detection, PDF-based signal extraction, and localized statistical analysis. The Canny Edge detection identifies features in a rasterized data product using a Gaussian filter and gradient calculation to extract signal photons. PDF-based analysis matches local probability density functions with the aggregate, thereby extracting probable signal points. The localized statistical method assigns thresholding values based on a weighted local mean of angular variances, where signal-noise deconvolution for threshold determination has been shown to enhance the filtered product. These approaches have demonstrated the ability to remove noise and subsequently provide accurate surface (ground/canopy) determination. The results presented here are based on analysis of multiple data sets acquired with the high altitude NASA MABEL system onboard an ER-2, which provided recent surveys over vegetated, desert and urban locations.

8379-27, Session 6

A novel range ambiguity resolution technique applying pulse-position modulation in time-of-flight ranging applications

P. Rieger, A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria)

Time-of-Flight range measurements rely on the unambiguous assignment of each received echo signal to its causative emitted pulse signal. The maximum unambiguous measurement range depends on the signal group velocity in the propagation medium and the source signals’ pulse repetition interval. When this range is exceeded an echo signal and its preceding pulse signal are not associated any longer and the result is ambiguous. We introduce a novel, two-stage approach which significantly increases the maximum unambiguous measurement range by applying a specifically coded pulse-position-modulation scheme to the train of emitted pulses in the first step. In the second step the analysis of resulting measurement ranges allows the unambiguous decision for the correct ranges. In this regard we also present a unique feature of a group of digital codes which helps to enhance detection robustness. Results are given on the basis of time-of-flight measurements from scanning LIDAR, where this technique has been implemented for the first time.

8379-28, Session 6

A calibration-and-error correction method for improved texel (fused lidar/digital camera) images

B. Bennett, S. E. Budge, Utah State Univ. (United States)

The fusion of imaging lidar information and digital imagery results in 2.5-D (depth) surfaces covered with texture information. Called “texel images,” these datasets, when taken from different viewpoints, can be combined to create 3-D images of buildings, vehicles, or other objects. These 3-D images can then be further processed for automatic target recognition, or viewed in a 3-D viewer for tactical planning purposes.

This paper presents a procedure for calibration, error correction, and fusing of lidar and digital camera information from a single hand-held sensor to create accurate texel images. A brief description of a prototype sensor is given, along with calibration technique used with the sensor, which is applicable to other imaging lidar/digital image sensor systems. The method combines systematic error correction of the lidar data, correction for lens distortion of the digital camera image, and fusion of the lidar to the camera data in a single process. The result is a texel image acquired directly from the sensor. Examples of the resulting images, with improvements from the proposed algorithm, are presented.

8379-29, Session 6

Measurement of transient dynamics with a scannerless infrared laser Doppler vibrometer

J. M. Kilpatrick, Advanced Systems & Technologies, Inc. (United States)

Short lived structural vibrations can play a key role in the dynamic behavior of computer disks, turbine blade and wing tip flutter, and in various forms of destructive or structural shock wave dynamics. The ability to capture transient structural deformation and vibrations is however currently limited by the XY scanning method employed in traditional single beam laser Doppler vibrometers, whose basic design and operation have changed little since their introduction. In this presentation we show how current developments in VLSI electronics and telecommunications fiber optic technology support development of a scannerless imaging vibrometer, capable of capturing full field structural dynamic phenomena at megahertz frame rates. We demonstrate practical application of the system to several key areas which entail transient dynamic phenomenon, including shock induced structural deformation and the aero-elastic disturbance associated with sound-in-flight.

8379-30, Session 6

An unsupervised classification for full-waveform lidar point data using IHSL transform and the FCM algorithm

J. Wang, C. Li, L. Tang, M. Zhou, The Academy of Opto-Electronics (China)

In this paper, the IHSL transform and the fuzzy C-means (FCM) classification algorithm are combined together to perform the unsupervised classification for full-waveform LiDAR point. At the beginning, based on the full-waveform LiDAR data, we decomposed the backscattered pulse waveform and abstracted each component in the waveform after the preprocessing of noise detection and waveform smoothing. And by the time flag of each component acquired in the decomposition procedure we calculated the three dimension coordination of the component. Then the components' waveform properties, including amplitude, width and cross-section, were uniformed respectively and formed the Amplitude/Width/Section space. We apply the IHSL colour transform to the above space to find a new space, RGB colour space, which has a uniform distinguishability among the parameters and contains the whole information of each component in Amplitude/Width/Section space. Then the fuzzy C-means algorithm is applied to the derived RGB space to complete the LiDAR point classification procedure. The main advantages of this method are that the IHSL transform removed the correlation between amplitude and cross-section as well as the parameters in the RGB colour space have similar interclass distinguishability. So it could achieve a high performance in the point segmentation algorithm, and since we could treat the parameters in the same way, the classification procedure can be simplified. The experiments show that this method could provide an improved classification result compared with the method which uses the Amplitude/Width/Section space directly during the segmentation procedure. And the classification result could probably be better applied in later target detection and identification.

8379-31, Session 7

A wide angle bistatic scanning lidar for navigation

X. Zhu, D. Aikman, C. Bell, A. M. DesLauriers, L. Gagnon, M. Guibert, M. Jamieson, B. Shadid, Neptec Design Group Ltd. (Canada); S. Gemme, L. Ilinca-Ignat, Canadian Space Agency (Canada)

Scanning LIDARs are widely used for 3D image based applications for navigation due to the advantage of using low laser power and immunity to the solar background. The optics of conventional scanning LIDARs are generally monostatic, i.e. launch beam and return beam share the same optical path in scanning optics. As a consequence, LIDARs with monostatic optics suffer poor performance at short range (e.g. <5m) due to scattering from internal optics and insufficient dynamic range of a LIDAR receiver. The drawback is undesirable for rover navigation since it is critical for rovers to see short range. It is also an issue for LIDARs used in applications involving aerosol penetration since the scattering from close by aerosol particles can disable LIDARs at short range.

To overcome these limitations, Neptec has previously developed a scanning LIDAR, called TriDAR, with triangulation optics that is capable for high speed scanning. In this paper, the reported design of the WABS (wide angle bistatic scanning) LIDAR is a major advance over the TriDAR design. While it retains the design of bistatic optics in which launch beam path and return beam path are separated in space, it greatly improves LIDAR performance in term of field-of-view, receiving aperture and sensor size.

The WABS design has been prototyped under contract to the Canadian Space Agency to demonstrate navigation tasks aboard a lunar rover. It has demonstrated good performance of FOV (45°x60°) and short range (<0.5m), both are important for rover navigation and hazard avoidance. We will discuss design objectives, and also present test results.

8379-32, Session 7

Slant path 1.5µm-range gated imaging of static and moving targets

O. Steinvall, M. Elmqvist, O. K. Gustafsson, K. Karlsson, Swedish Defence Research Agency (Sweden)

This paper will report experiments and analysis of slant path imaging using 1.5 µm gated imaging. The investigation is a follow up on the measurement reported last year at the laser radar conference at SPIE Orlando.

The sensor, a SWIR camera was collecting both passive and active images along a 2 km long path over an airfield. The sensor was elevated by a lift in steps from 1.6-13.5 meters. Targets were resolution charts and also human targets. The human target was holding various items and also performing certain tasks some of high of relevance in defence and security. One of the main purposes with this investigation was to compare the recognition of these human targets and their activities with the resolution information obtained from conventional resolution charts.

The turbulence was measured along the path with anemometers and scintillometers. The camera was collecting both passive and active images in the SWIR region.

The paper will present images for both passive and active modes obtained at different elevations and discuss the results from both technical and system perspectives.

8379-33, Session 7

Improvement of the sensitivity of lidar with sensor-head of thumb size by using optical fiber preamplifier

D. Inoue, T. Ichikawa, H. Matsubara, X. Mao, M. Maeda, C. Nagashima, M. Kagami, Toyota Central R&D Labs., Inc. (Japan)

Laser intensity direction and ranging (LIDAR) is used for environmental measurement and automotive application, because LIDAR has higher resolution than radio detection and ranging (RADAR.)

We developed a LIDAR, whose sensor head is as small as 22 cc in spite of including scanning mechanism. This LIDAR system has not only small body but also high sensitivity.

Our LIDAR system is based on time of flight measurement, and consists of optical fiber. The feature of our system is utilization of optical amplifier for both transmitter and receiver, and optical amplifier enabled us to exceed the detection limit of thermal noise. Usually the detection limit of LIDAR is determined by thermal noise, because avalanche photo diode (APD) and trans impedance amplifier (TIA) detects received signal directly. In the case of our LIDAR system, received signal is amplified with optical fiber amplifier in front of photo diode and TIA. So, our LIDAR system can boost the signal level before weak signal is depleted by thermal noise. There is condition that noise figure of combination of optical fiber amplifier and photo diode is superior to noise figure of avalanche photo diode.

As a result, the detection limit of our LIDAR system is determined by shot noise.

We improved the optical system and signal processing system, so that we can detect relative velocity of vehicles.

This small and highly sensitive measurement technology shows great potential as LIDAR with optical preamplifier.

8379-34, Session 7

Compact high-speed scanning lidar system

C. Dickinson, MacDonald, Dettwiler and Associates Ltd. (Canada); M. Hussein, J. Tripp, Optech, Inc. (Canada); M. Nimelman, MacDonald, Dettwiler and Associates Ltd. (Canada); S. Gemme, Canadian Space Agency (Canada)

Navigational Guidance Navigation & Control (GN&C) sensors systems currently being offered are a compromise, trading system performance with compactness, efficiency or operation under all lighting conditions. The compact High Speed Scanning Lidar (HSSL), however, provides the first GN&C sensor to meet all of these specifications in a single package. The eye-safe HSSL's fast scanning speed, low volume and low power make it the ideal choice for a variety of real-time and non-real-time applications including:

- Vehicle Guidance and Navigation

- Orbiter Rendezvous
- Spacecraft Landing / Hazard Avoidance
- Obstacle Detection
- 3D Mapping

The HSSL is comprised of two main hardware units: Sensor Head and Control Unit. In a rover application, the Sensor Head mounts on the top of the rover while the Control Unit can be mounted on the rover deck or within its avionics bay. An Operator Computer is used to command the lidar and immediately display the acquired scan data.

This pioneering lidar concept is the result of an extensive trade study conducted during the initial phase of an exploration rover program. The design utilizes an innovative scanner coupled with a compact fiber laser and high-speed timing electronics. Compared to existing compact lidar systems, distinguishing features of the HSSL include its high scan speed, high accuracy and resolution and large field of view. HSSL represents a leap forward in GN&C sensor technology, making it an ideal candidate for high performance applications both terrestrially and in space.

8379-35, Session 7

Advanced compact 3D lidar using the high-speed fiber coupled pulsed laser diode and high-accuracy timing discrimination readout circuit

M. Lee, S. Baeg, S. Park, Korea Institute of Industrial Technology (Korea, Republic of)

As we presented in DSS 2011, we have developed the 3D LIDAR designated as the KIDAR-B25 which is using the new scanning mechanism to measure the 3D imaging data based on optically coupled horizontal and vertical scanning structures. As a result of last year outdoor experiments for the evaluation of KIDAR-B25 whole performance, we could know some limitations and problems. Thus, we focused into the improvement of the systemic quality and stability such as timing accuracy, precision and high speed distant measurement rates regardless of vibration effect. For the realization of previous goals, we mainly described two improvements comparing with the Kidar-b25 in this paper. First, we have changed the timing discrimination circuit which can detect the input signal by setting the threshold level into the constant fraction discriminator (CFD). This readout circuit can be reduced the random walk error. Second, we newly developed the optical transceiver which is based on multi-channel fiber coupled pulsed laser diode and single SiAPD (pulse width :5~10ns , wavelength : 905nm, maximum repetition rate : 200KHz, fiber coupled Laser diode : peak power: 60W). The optical assembly and scanning mechanism are same one which is already designed. In addition to timing performance, we could measure the wide range of vertical plane up to ±15o as the rotated whole horizontal plane (360 o) with 0.06o step (max distant: 50m).The experimental results show that the ranging performance and system stability have been improved comparing with last version of KIDAR-B25. We hopefully expect that it will be usefully used to realize the autonomous navigation of the robots for detecting and avoiding the moving objects with real time.

8379-36, Session 8

Development of a ROIC for lidar on planetary lander by CMOS technology

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In recent years, LIDAR has been used as a navigation sensor of a planetary lander. Especially, a wide dynamic range is necessary for applications of a planetary lander. For instance, the asteroid sample return mission “Hayabusa” required 60 dB for the dynamic range of the receiving system, because it was necessary to measure the distance of 50 m-50 km. On the other hand, LIDAR can be used also as a use of obstacle detection. As an obstacle detection sensor of a lander, resolution of 10 cm or more is required.

For the planetary lander, ISAS/JAXA is developing a Readout Integrated Circuit (ROIC) for a LIDAR reception by CMOS technology. The main function of the device is timing detection of light pulses in a 60-dB dynamic range at the input level. In addition, in order to realize resolution of 10 cm with low digital circuit drive frequency (20-30MHz) for low power consumption, the ROIC has adopted TAC for the interpolation. This ROIC is manufactured in the 0.35um process of CMOS which has many experiences about radiation resistance. The dynamic range of this device is already realized from 2 fC to 3000 pC. Timing dispersion 1σ of the pulse detection reaches less than 300ps, under optimized gain for a signal level. This report introduces the outline of ROIC and reports the evaluation experiment of the latest version of ROIC.

8379-37, Session 8

An overview of heat dissipation technologies in classical lidar instruments

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With the rapid development of laser and photoelectron technologies, the issues of thermal management and thermal control technology in LiDAR instruments emerged, especially after the present of laser diode with high power, high luminance and high efficiency.

According to the thermal issues in laser instruments, this paper provides an overview of the thermal control systems in several LiDAR instruments, which includes ALAND (Atmospheric Laser Doppler Instrument) on ESA's ADM-Aeolus Explorer Mission, GLAS (Geoscience Laser Altimeter System) on ICESat (Ice, Cloud and Land Elevation Satellite), LIDAR (Light Detection and Ranging) system on Clementine mission, MOLA II (Mars Orbiter Laser Altimeter) on Mars Global Surveyor, NRL (Near Laser Rangfiner) on NEAR (Near Earth Asteroid Rendezvous) spacecraft, MLA (Mercury Laser Altimeter) on MESSENGER (Mercury Surface, Space Environment, Geochemistry, and Ranging) mission, LOLA (Lunar Orbiter Laser Altimeter) on LRO (Lunar Reconnaissance Orbiter), SELENE Lunar Laser Altimeter (LALT) on Japanese lunar orbiting explorer SELENE (SELenological and Engineering Explorer), SPARCLE (SPAce Readiness Coherent Lidar Experiment) on NASA's NMP (New Millennium Program) EO-2 (Second Earth Orbiter) mission, and LELA (Lunar Explorer Laser Altimeter) on Change-1 spacecraft. Detailed descriptions of those thermal control systems are given.

Those thermal control systems were analyzed and summarized. Comparisons among those thermal control systems are made in this review to help illustrate the versatile range of different design choices available for tailoring future LiDAR instruments to address numerous science objectives on upcoming detecting mission opportunities.

8379-38, Session 8

Laser sources for lidar applications

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Advanced LIDAR applications such as next gen:

- Micro Pulse
- Time of Flight (e.g., Satellite Laser Ranging)
- Coherent and Incoherent Doppler
- High Spectral Resolution
- Differential Absorption (DIAL)
- photon counting LIDAR

are placing more demanding requirements on conventional lasers (e.g., increased rep rates, etc.) and have inspired the development of new types of laser sources.

In this paper, we report on the development of compact, highly efficient, high power all-solid-state diode pulsed pumped ns lasers, as well as, high average power/high pulse energy sub nanosecond (<1ns) and picosecond (<100ps) lasers for these next gen LIDAR applications.

8379-39, Session 9

Feasibility study for airborne fluorescence lidar bathymetry

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There is a demand from the authorities to have good maps of the coastal environment for their exploitation and preservation of the coastal areas. The goal for environmental mapping and monitoring is to differentiate between vegetation and non-vegetated bottoms and, if possible, to differentiate between species.

Airborne lidar bathymetry is an interesting method for mapping of shallow underwater habitats. In general, the maximum depth range for airborne laser exceeds the possible depth range for passive sensors. Today, operational lidar systems are able to capture the bottom (or vegetation) topography as well as estimations of the bottom reflectivity using e.g. reflected bottom pulse power. In this paper we study the possibilites and advantages for environmental mapping, if laser sensing would be further developed from single depth sounding systems to include multiple emission wavelengths and fluorescence. Our results show that an airborne fluorescence lidar has several interesting features which might be useful in mapping of underwater habitats. An example is the laser induced fluorescence giving rise to the emission spectrum which could be used for classification together with the elastic lidar signal.

In the first part of our study, vegetation and substrate samples were collected and their spectral reflectance and fluorescence were subsequently measured in laboratory. A laser wavelength of 532 nm was used for excitation of the samples. The choice of 532 nm as excitation wavelength is motivated by the fact that this wavelength is commonly used in bathymetric laser scanners and that the excitation wavelengths are limited to the visual region as e.g. ultraviolet radiation is highly attenuated in water. The second part of our work consisted of theoretical performance calculations for a potential real system, and comparison of separability between species and substrate signatures using selected wavelength regions for fluorescence sensing.

8379-40, Session 9

The impact of sea state conditions on airborne lidar bathymetry measurements

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Due to a large number of available Airborne Lidar Bathymetry (ALB) surveys datasets and the scheduled future surveys, there is a growing need from coastal mapping communities to estimate the accuracy of ALB as a function of the survey system and environmental conditions. Knowledge of the ALB accuracy can be also used to evaluate the quality of products derived from ALB surveying. This paper presents theoretical and experimental results focused on the relationship between the sea surface conditions and the accuracy of ALB measurements. The simulated environmental conditions were defined according to the typical conditions under which successful ALB surveys can be conducted. The theoretical part of the research included simulations using optical system design software, where the ray-path geometry of the laser beam was monitored above and below the water surface. Wave-tank experiments were conducted to support the simulation. A cross section of the laser beam was monitored underwater using a green laser with and without wind-driven waves. The results of the study show that capillary waves and small gravity waves distort the laser footprint, and large gravity waves stretch the laser footprint but do not distort the laser beam. Because sea-state condition is related to wind at a first-order approximation, it is possible to suggest wind speed thresholds for different ALB survey projects that vary in accuracy requirements. If wind or wave information were collected during an ALB survey, then it is possible to evaluate the change in accuracy of ALB survey due to different sea surface conditions.

8379-41, Session 9

Remote topographic collections in an estuarine intertidal zone using a single photon counting imager

S. R. Greenfield, D. C. Thompson, Los Alamos National Lab. (United States); A. Garrett, Savannah River National Lab. (United States)

Estuarine intertidal zones are characterized by complex networks of tidal creeks and marshes, which typically dry out and re-flood twice a day. Quantitative understanding of transport and retention of pollutants in these systems requires accurate topographic data for use in interpretation of field collections and for construction of computational domains used for hydrodynamic simulations. Salt-water marsh grasses are often dense and a meter or more in height, which limits the accuracy of topographic mapping using conventional LIDAR. This paper describes initial results of an intertidal zone topographic collection using a single photon imaging sensor called Nocturnal Camera (NCam), developed at Los Alamos National Laboratory. Traditional LIDAR collects data in a point-by-point, rastering fashion and analyzes an analog return waveform. By contrast, we build up 3D imagery one photon at a time over the entire image, with sub-ns time resolution and using flood illumination with a low-average-power, short-pulse 532-nm laser operating at 1 MHz PRF. Because of the virtually noiseless process of accumulating photon statistics in this manner, NCam-based LIDAR should be able to accurately determine the ground level through thick, low-lying foliage. The performance of NCam based on a preliminary, limited-area collection from a stationary, elevated platform will be discussed with particular emphasis on NCam’s accuracy in locations with dense marsh grass where relatively poor performance by LIDAR-based systems would be expected. NCam’s topography will be compared to ground truth from Real Time Kinetic (RTK) GPS-based surveys, and system performance will be extrapolated to operation from an airborne platform.

8379-42, Poster Session

Ultraviolet scanning Raman lidar with fast telescope for measurements of water vapor and aerosols in lower atmosphere

F. Gao, S. Stanic, T. He, Univ. of Nova Gorica (Slovenia); D. Hua, Xi’an Univ. of Technology (China)

This work reports on the design, construction and commissioning of a UV scanning Raman lidar at Otlica observatory in Slovenia. A fast parabolic mirror (diameter = 800 mm; focal length = 410 mm) and a tripled Q-Switched Nd:YAG pulsed laser were mounted on a common frame steerable in the zenith angle (angular resolution = 0.1 deg). UV-enhanced 1000 μm core optical fiber was used to transfer the return signal from the telescope to the polychromator. In order to maximize the signal, custom optics using a low f-number aspheric lens was designed to focus the light into the fiber. The fiber output was then collimated and split into three parts. The light beams used for the detection of vibrational Raman signals from backscattering on N2 and H2O molecules were separated using 5 nm bandwidth interference filters combined with dichroic beam splitters. Hamamatsu H1949 and H2431 PMT’s were used as detectors, while the data was sampled using Licel TR40-160 transient recorders. System functionality was assessed in a series of preliminary experiments. Measurements at various angles with a summation time

of 2.5 hours show that aerosol optical variables (extinction, backscatter and lidar ratio) can be retrieved up to a range of 5 km and that the water vapor information (mixing ratio and relative humidity) can be determined up to a range of 4 km. The performance of the system was verified and calibrated using co-located radiosonde data.

8379-43, Poster Session

Performance improvement of real-time 3D imaging ladar based on a modified array receiver

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In the previous study, we have demonstrated the first development result of the real-time 3D imaging LADAR (LAser Detection And Ranging) which can obtain the 3D data with long range, high resolution, and high speed using linear array receiver. The system consists of in-house-made key components. The linear array receiver consists of the previously reported APD (Avalanche Photo Diode) array and the ROIC (Read Out Integrated Circuit) array assembled in one package. Moreover, we developed the transmitting optics using pupil divide method which realizes a uniform illumination on a target. By combining these devices with the one dimensional fast scanner, we realized a 256 256 pixels range imaging with an on-line frame rate of more than 10 Hz at a distance of more than 1 km. In this paper, we show that the refined image results due to improvement of ROIC performance.

8379-44, Poster Session

3D scene reconstruction with monocular visual odometer based on inverse perspective mapping

Y. Cao, Y. Feng, L. Wei, B. Lei, National Univ. of Defense Technology (China)

Abstract: In the process of 3D reconstruction of the target scene with the moving vehicle-borne laser scanner, a monocular visual odometer is used to locate the exact position of the moving vehicle instead of the traditional device that the combination of GPS and Inertial Navigation System (INS). An attitude sensor, a camera and a laser scanner are located on the same platform which is installed on the vehicle.The characteristic points between two adjacent images obtained from the camera can be calculated by the speeded up robust features (SURF) algorithm. After that, By means of the random sample consensus (RANSAC) algorithm, the parameters of translation and rotation between two adjacent images can be concluded. Accordingly, the movement distance and the course of the vehicle can be worked out. On this basis, the original point cloud data got by laser scanner can be registered as a reference to the traveling track of the running vehicle, and the 3D reconstruction of the target scene is established. Simulation result shows that the accuracy of camera's initial attitude influences the location accuracy of monocular visual odometer seriously. So in our system, the camera's attitude is measured by the attitude sensor and the relationship between the world coordinate and the image coordinate of the camera can be described by a specific matrix, then the perspective effect of SURF characteristic points of images are removed by means of the inverse perspective mapping algorithm. Experiment result shows that, with regard to a 282m-long closed circular track of vehicle around a building, the location error between start point and end point is 1.5m. Consequently, the method of 3D scene reconstruction described in this paper is easy to operate, time-efficient, low cost, and the accuracy in reconstructing 3D scene is demonstrated.

8379-45, Poster Session

Fusion of 3D imaging ladar and binocular stereo vision for improved 3D measurement

J. Yang, X. Wang, S. Qin, C. Hu, Z. Huang, National Univ. of Defense Technology (China)

Abstract: 3D imaging ladar and binocular stereo vision are two typical 3D scene geometric information measurement methods. But these methods have their own limitations such as ladar has lower spatial resolution and stereo vision has poor disparity maps estimation in long distance. To overcome these limitations we introduce a fusion of two 3D measurement techniques: 3D imaging ladar and binocular stereo vision. By mapping the ladar-depth images to stereo images the correspondence between ladar images and stereo camera pair are found so the ladar depth measurements can be linked to the image pairs. Also in the same framework a method is developed to constrain stereo matching algorithm and make it time efficient. Experiment results show that in this way higher spatial resolution is gained than by only using the ladar and higher quality dense stereo disparity maps than using standard stereo methods.

8379-46, Poster Session

A modified ladar system with a Geiger mode APD to remove a dead time problem

S. E. Jo, H. J. Kong, T. H. Kim, KAIST (Korea, Republic of); J. Jin, J. W. Kim, J. Kim, Korea Research Institute of Standards and Science (Korea, Republic of)

A laser radar (LADAR) system with a Geiger mode avalanche photodiode (GAPD) has been used widely because of high detection sensitivity. However, it needs a certain amount of time to receive the following signals after detecting the previous one. The dead time is usually 10 ns to 10 μs, determined by material composition of the detector and design of quenching circuits. Therefore, when we measure the objects placed closely each other along the optical axis using the LADAR system with the GAPD, it is difficult to separate them clearly owing to the dead time problem.

In this paper, we suggested a modified LADAR system with the GAPD to remove the dead time problem by adopting an additional linear mode avalanche photodiode (LAPD) as a complementary detector. Because the LAPD does not have the dead time although it has relatively low detection sensitivity, the proposed system can measure the objects placed within the dead time with high detection sensitivity. One of the possible examples is to detect hidden objects behind partially transparent blinds.

A light emits from the pulsed laser of a light source, and then it delivers into a fast photodiode to generate a start signal. The most of laser pulses are directed to the target and scattered from surfaces of targets. The scattered light in the field-of-view of the system is divided by a polarizing beam splitter, and then incident to two different types of APDs, GAPD and LAPD. GAPD receives signals from the target with high sensitivity, and then the signals scattered in the dead time zone are detected by LAPD. The obtained signals are analyzed at the same time. Finally the signals scattered from objects placed within the dead time can be distinguished clearly.

8379-47, Poster Session

Improvement of SNR by temporal filtering method in ladar system using two Geiger-mode avalanche photodiodes

T. H. Kim, H. J. Kong, S. E. Jo, KAIST (Korea, Republic of)

In this paper, a new method to improve the SNR by temporal filtering method in LADAR system using two Geiger-mode avalanche photodiodes (GmAPDs) is proposed. A GmAPD or a GmAPD focal plane array is used as a detector in long-range LADAR system due to its high sensitivity. On the other hand, the detector generates identical electric signals corresponding to laser-return pulse and noise. Therefore, Time-correlated single-photon counting (TCSPC), which is a repetitively pulsed statistical sampling technique, is used to distinguish signals and noise. Nevertheless, if there is lots of noise, it cannot distinguish signals and noise. So, it needs additional ways to reduce noise. In general a narrow optical band pass filter and a gate mode operation are used to reduce the noise. The lots of background noise is limited because the narrow optical band pass filter must be wide enough to accommodate wavelength shifts caused by variations in both temperature and incidence angle. Even though using the gate mode operation, it needs to set the gate time more than the signal returning time. Therefore, there is noise within gate time. Additional image processing steps are essential for noise elimination.

The new method is implemented by using two GmAPDs with beam splitter and employing AND process to their ends. Then, timing circuitry receives the electrical signals only if each GmAPDs generates the electrical signals simultaneously. Though this method decreases the energy of a laser-return pulse scattered from the target, it is highly effective in reducing the false-alarm probability because of the randomly distributed noise on the time domain. Then it needs not any image processing steps.

The experiments are performed to prove the advantage of the new method proposed with varying the time bin size. The experimental results represent that the improvement of SNR.

8380-01, Session 1

Retro-reflector diversity effects in free-space optical links

W. S. Rabinovich, R. Mahon, C. I. Moore, M. R. Suite, M. S. Ferraro, L. M. Wasiczko Thomas, P. G. Goetz, U.S. Naval Research Lab. (United States)

Optical scintillation is an effect that limits the performance of many optical systems including imagers and free space optical communication links. Scintillation can be especially severe for optical retro-reflectors. This can limit the range of links based on modulating retro-reflectors. In this work we examine the effects of retro-reflector diversity on optical scintillation. This technique uses multiple retro-reflectors, separated by a distance larger than the atmospheric coherence size and illuminated by one interrogating beam, to reduce the scintillation index. We examine the dependence of scintillation index on the number of retro-reflectors, their separation and the degree of coherent interference at the receiver.

Data was taken in the field at three different sites: the Naval Research Laboratory's Chesapeake Bay Detachment, where both over land and over water measurements were made, the Fort AP Hill Laser test Range and China Lake, California. We show that multiple retro-reflectors can reduce the scintillation index on double-pass links. We demonstrate that when retro-reflectors are spaced too closely, coherent interference can increase the scintillation index and greatly expand its frequency content. We also examine the effects of retro-reflector diversity on the margin needed for modulating retro-reflector data links

8380-02, Session 1

Miniature lasercomm module for integration into a small, unmanned, aerial platform

M. J. Vilcheck, H. R. Burris, Jr., L. D. Epp, C. I. Moore, W. R. Smith, Jr., L. L. Summers, L. M. Wasiczko Thomas, U.S. Naval Research Lab. (United States)

The U.S. Naval Research Laboratory (NRL) is developing a small lasercomm terminal for both direct lasercomm and communication to a modulated retroreflector (MRR). A gimbal from Cloud Cap Technology serves as the terminal positioner, which is to be integrated onto a small, unmanned airborne vehicle. A lasercomm module must be developed that meets size, weight, power, and optical performance requirements. The first version of the module incorporates the shared optics, the tracking optics, and the tracking detector. This module was designed, fabricated, assembled, and integrated into the Cloud Cap gimbal. After integration, the tracking signals were measured in the lab to establish the field of view and response to pointing errors. Design work for an updated module that includes the lasercomm receiver is also described.

8380-03, Session 1

Fade and surge asymmetry of direct single-mode-fiber coupled free-space optical signal under weak atmospheric turbulences

Y. Arimoto, National Institute of Information and Communications Technology (Japan)

A new category of compact free-space optical (FSO) communication terminal in which diffraction limited laser beams are directly transmitted from and coupled into a single mode fiber (SMF) has been developed at NICT to realize multi-Gbps to Tbps class point-to-point wireless optical link. This paper reports propagation characteristics of direct SMF-coupled FSO terminals based on the data at the recent outdoor demonstration experiments over 100-500 m link distance under medium to weak atmospheric turbulence conditions. The results show highly asymmetric surge/fade distribution in SMF-coupled signal intensities due to phase interference at the SMF receiving aperture, which is different from the result in the normal irradiance scintillation distribution, such as Gamma-Gamma distribution or log-normal distribution. These experimental data indicate that reliable FSO links, to be comparable and replaceable to fiber optic links, should be operated under the weak atmospheric turbulence environments where scintillation index is less than 0.1. This requirement is also valid to maintain mutual beacon tracking to assure precise tracking/pointing accuracy required for the direct SMF coupling.

8380-04, Session 1

Automating a lasercomm terminal on a small, unmanned, aerial platform

W. R. Smith, Jr., H. R. Burris, Jr., M. J. Vilcheck, C. I. Moore, L. L. Summers, L. M. Wasiczko Thomas, U.S. Naval Research Lab. (United States)

No abstract available

8380-05, Session 1

Design simulation and analysis of a fiber-bundle-based optical wireless link

P. G. LoPresti, The Univ. of Tulsa (United States); D. Zhou, The Univ. of Oklahoma - Tulsa (United States); Z. Shi, The Univ. of Tulsa (United States); H. Refai, The Univ. of Oklahoma - Tulsa (United States)

A novel receiver and transmitter that utilize fiber bundles are under development to address the challenges associated with acquiring and maintaining a free-space optical link between mobile platforms in the presence of vibration and atmospheric turbulence. The fiber bundles allow for greater misalignment tolerance at the receiver and greater control over the spatial area covered by the transmitted beam upon reaching the receiver. This paper reports on a simulation-based investigation of design choices that optimize the performance of the system under several operating scenarios. The simulation incorporates prior experimental data into the theoretical calculations for optical propagation to better describe the performance of the physical designs. For a given link length and available power, the coverage area and collected power are controlled by the pattern of transmitters, beam divergence, and the receiver construction. The investigation finds that the coverage area of the receiver can be optimized for a given link length by proper choices of these parameters, and that similar parameters may provide near optimal performance at other wavelengths. Trade-offs between choices of the key parameters are explored as a function of link length. The results provide guidance on the further development of the overall system.

8380-06, Session 2

Analysis of link performance for the FOENEX laser communications system

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A series of experiments were conducted to validate the performance of the free-space optical communications (FSOC) subsystem under DARPA's Free-space Optical Experimental Network Experiment (FOENEX) program. The FSOC subsystem couples 10-cm, Adaptive Optics (AO) FSO terminals to high-performance, 10-Gbps optical modems for target operation at ranges exceeding 50 and 200 km in air-to-ground and air-to-air configurations, respectively.

Over six days in May and June 2011, bidirectional links at ranges of 10 and 17 km were characterized during different periods of the day to evaluate link performance at different link ranges and under a variety of turbulence conditions. A scintillometer characterized local turbulence conditions by recording the atmospheric structure constant, Cn2, while numerical predictions based on the Weather Research and Forecast model predicted Cn2 profiles.

This paper will present the test configuration, discuss the performance of the FSOC subsystem, and compare it to the current link models and theory. In particular, the performance impact from the AO system and latest modem generation will be addressed. Critical data products to be analyzed include power in bucket, power in fiber, Strehl Ratio, scintillation index, probability density functions, and beam diameter. Finally, this paper will summarize the impact of turbulence conditions on the FSOC subsystem and methods for estimating performance under different link distances and turbulence conditions.

8380-08, Session 2

High-performance free-space optical modem hardware

J. E. Sluz, J. C. Juarez, C. Bair, R. L. Oberc, The Johns Hopkins Univ. Applied Physics Lab. (United States); R. Venkat, Princeton Univ. (United States); D. Rollend, D. W. Young, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Maintaining performance at 10 gigabit rates over free-space optical (FSO) channels requires hardware that has excellent receiver sensitivity and does not magnify issues resulting from fluctuating and faded channels. This paper describes key aspects of modem hardware designed to operate in links of up to 200 km. The hardware serves as a bridge between standard 10 gigabit Ethernet client data systems and FSO terminals. The modem hardware alters the client data in rate and format for optimal transmission over the FSO link by applying forward error correction (FEC) processing, differential phase shift keying (DPSK) formatting and optical automatic gain control (OAGC) in order to obtain sensitivities at approaching -48 dBm while in the presence of turbulent optical conditions that create large dynamic range optical power fades.

The FSO transmit portion of the modem hardware consists of a FEC encoder and a DPSK transmitter with a tunable laser source. The receive portion of the modem consists of an OAGC, a DPSK receiver, and a FEC decoder. An integral system controller provides data collection and system control as well as an automated built in test capability. Critical design features of the hardware that have been tailored for the FSO channel include rapid optical gain control, Ethernet idle generation in the presence of channel loss, rapid link establishment after extended outages, and a DPSK receiver bias control system that is robust against rapid power fluctuations even in the presence of varying temperature and wavelength conditions.

8380-08, Session 2

Development of a large area InGaAs APD receiver based on an impact ionization engineered detector for free-space lasercomm applications

H. R. Burris, Jr., M. S. Ferraro, W. Freeman, C. I. Moore, J. L. Murphy, W. S. Rabinovich, W. R. Smith, Jr., L. L. Summers, L. M. Wasiczko Thomas, M. J. Vilcheck, U.S. Naval Research Lab. (United States); W. R. Clark, W. D. Waters, OptoGration Inc. (United States)

No abstract available

8380-09, Session 2

Characterization of InGaAs avalanche photodiode arrays with varying geometries for free-space optical communication

M. S. Ferraro, H. R. Burris, Jr., R. Mahon, W. S. Rabinovich, W. Freeman, J. L. Murphy, P. G. Goetz, C. I. Moore, L. M. Wasiczko Thomas, U.S. Naval Research Lab. (United States); W. R. Clark, W. D. Waters, OptoGration Inc. (United States)

Photodiode arrays are instrumental in providing pointing and tracking information for free space optical communication systems. Recent advances in the fabrication and development of low noise, high bandwidth avalanche photodiode (APD) arrays have enabled these devices to be used not only as position sensitive detectors (PSD) for tracking but also as communications receivers. In a collaborative effort with Optogration, Inc., the U.S. Naval Research Laboratory has developed avalanche photodiode arrays with three different geometries: a 3x3 square pixel array, a centered hexagonal pixel array, and a 5 pixel concentric array configuration with a center pixel and four periphery pixels. The characterization and performance of each array geometry will be described along with associated front-end and digital electronics. Design tradeoffs for maximizing the performance of a given array geometry will also be discussed.

8380-10, Session 2

Evaluation of optical transceivers for mobile FSO applications

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In order for mobile optical transceivers to communicate, the transceivers must be able to acquire and maintain a free-space optical link between them despite misalignments due to movement and the effects of atmospheric turbulence. Recently, novel transmitters and receivers, along with specifically designed control algorithms, were proposed that incorporated a fiber-bundle approach for improving the ease of acquiring and maintaining the link between two transceivers. Preliminary transmitter and receiver nodes have been constructed for testing the capabilities of this approach. This paper investigates the performance of a transmitter and receiver pair through experimental methods. The performance is evaluated on several key parameters, including initial acquisition time, up time of the link when perturbed by movement or simulated atmospheric impairment, and the link recapturing time once a connection is lost. The dependence of the key parameters is evaluated for different levels and types of perturbations, as well as design choices at the transmitter and receiver. The results show that the optical control system successfully recovered and maintained the link while the receiver was in motion, although the performance was impacted by the angular

misalignment tolerance of the receiver. The strengths and limitations of the approach revealed by the experiments are also discussed, along with paths for further improvements.

8380-11, Session 3

Improved atmospheric characterization for free-space link analysis using numerical weather prediction

B. D. Felton, P. D. Hayes, R. J. Alliss, Northrop Grumman Corp. (United States)

The atmosphere distorts and degrades RF and FSO communications signals. Clouds, precipitation, turbulence, and inhomogeneities in atmospheric temperature and moisture all have the potential to disrupt communications through the atmosphere. However, there are strategies that can be employed to mitigate atmospheric impacts on communications networks such as FOENEX. These strategies require an accurate characterization of the atmosphere through which the communications links travel.

Atmospheric measurements provided by local instrumentation such as meteorological stations, radiosondes, and scintillometers are valuable for link characterization, but provide an incomplete picture of the atmosphere. During the FOENEX demonstrations, these in situ measurements were supplemented with Numerical Weather Prediction (NWP) simulations, which provided a time-varying, three-dimensional characterization of the atmosphere. The Weather Research and Forecasting (WRF) NWP model was used to simulate the weather conditions over the FOENEX test regions during the flights. The output of the simulations provided the high-resolution horizontal and vertical structure of the temperature, winds, and moisture for the test domain. The details of each simulation were dictated by model inputs that included daily weather conditions, terrain, and land usage. In addition, modifications were made within WRF to calculate the refractive index structure function, Cn2, directly from the standard NWP model parameters. This has proven to be a valuable tool for link characterization, since WRF can identify relatively thin layers of optical turbulence that are not fully captured by standard empirical Cn2 models. The results of these WRF simulations including comparisons with FOENEX test demonstration results will be presented at the conference.

8380-12, Session 4

Fast, compact, computer-free holographic adaptive optics

G. P. Andersen, F. Ghebremichael, HUA Inc. (United States); R. Gaddipati, P. Gaddipati, Centum Engineering (United States)

We have constructed a closed-loop adaptive optics system that operates at 100kHz without the need for a computer. The system uses a multiplexed hologram which is essentially pre-programmed with the response functions of each actuator in a given deformable mirror. An input beam incident on this hologram reconstructs a pair of focused beams - one for each actuator. The power ratio of each pair is directly related to the absolute phase of the wavefront for a particular actuator, so a simple feedback circuit between a fast photodetector array and the deformable mirror can provide fast, computer-free closed-loop correction.

We present results from a working holographic adaptive laser optics system (HALOS) incorporating a 32-actuator MEMS-based deformable mirror and an off-the-shelf, photon counting avalanche photodiode array. A simple digital circuit has been constructed to provide autonomous control and the entire system is no larger than a shoebox. Our results demonstrate that this device is largely insensitive to obscuration and in principle can run as fast with one actuator as with one million. We will further show how HALOS can be used in image correction, laser beam projection as well as phased-array beam combination.

8380-13, Session 4

Validity of using Gaussian Schell model for extended beacon studies

S. Basu, S. J. Cusumano, M. W. Hyde IV, M. A. Marciniak, S. T. Fiorino, Air Force Institute of Technology (United States)

In many military applications that use Adaptive Optics (AO) a point source beacon is ideally required at the target to measure and to correct for the wavefront aberrations caused by propagation through the atmosphere. However, it is rarely possible to create a point source beacon at the target. The “extended beacons” that are created instead have intensity profiles with a finite spatial extent and exhibit varying degrees of spatial coherence. The Gaussian Schell model might be a convenient way to model these extended sources because of its analytical tractability. The present work will examine the validity of using such a model by evaluating the scattered field from a rough surface target using a full wave electromagnetic solution (method of moments). The full wave electromagnetic calculation improves the fidelity of the analysis by capturing all aspects of the interaction of the laser with the target’s surface, i.e. shadowing/ masking, multiple reflections etc. A variety of rough surface targets with different roughness statistics will be analyzed. The full wave electromagnetic solutions will be compared against experimental data from a Complete Angle Scatter Instrument (CASI). This analysis will ultimately aid in understanding of the key parameters of extended beacons and how they can impact the overall performance of an AO system.

8380-14, Session 4

High contrast imaging in the presence of turbulence

B. A. Sickmiller, SAIC (United States); D. J. Sanchez, P. R. Kelly, Air Force Research Lab. (United States); D. W. Oesch, SAIC (United States)

High contrast imaging, also known as extreme adaptive optics, has been a topic of research in the astronomic community as an approach to image dim objects near bright objects, such as extra-solar planets. There are a variety of techniques ranging from coronagraphs, shaped pupils, pupil apodization, and the use of multiple deformable mirrors that have been employed to improve the contrast between the two objects. We integrated shaped pupils into our adaptive optics system. Here we will present experimental results exploring the viability of using our testbed to perform dim object detection using shaped pupils on in the presence of turbulence.

8380-15, Session 5

Near-surface turbulent temperature variances and anisotropy at multiple scales of motion

C. L. Klipp, U.S. Army Research Lab. (United States)

Atmospheric boundary layer turbulence occurs over a broad range of scales from the dissipation scale on the order of millimeters to the scale of the boundary layer on the order of kilometers. This mechanical turbulence transports and mixes heat and moisture, usually from the surface, which are responsible for optical turbulence. Although it is known that the small scale turbulent motion is isotropic and the large scale motion is anisotropic, not much is known about the degree and type of anisotropy over the whole range of turbulence scales. Anisotropy may explain certain propagation anomalies such as angle-of-arrival and beam wander effects that are not axis-symmetric. A better understanding of the statistical properties of the anisotropy may lead to better prediction of the conditions which lead to different degrees of distortion as well as to better strategies for mitigation of distortion.

This presentation will look at the degree and nature of anisotropy at a

variety of elevations from the surface up to 50m, focusing on the lowest 10m over the course of the day. In addition, the turbulent temperature variances over the range of turbulence scales will be correlated with anisotropy properties as well as velocity variances and covariances. The data are from sonic anemometers at the CASES99 60 m main tower near Leon, KS as well as from the 3DTS array of sonic anemometers deployed at White Sands Missile Range in 2008.

8380-16, Session 5

Atmospheric characterization with multiwavelength laser beams over tactical and long-range propagation paths

M. A. Vorontsov, Univ. of Dayton (United States); G. W. Carhart, U.S. Army Research Lab. (United States); V. S. R. Gudimetla, Air Force Research Lab. (United States); S. L. Lachinova, Optonicus (United States); T. Weyrauch, E. E. Polnau, Univ. of Dayton (United States); J. J. Liu, U.S. Army Research Lab. (United States)

We report results of experimental measurement and analysis of atmospheric effects on laser beam propagation over two distinctive propagation paths: a long-range (149 km) propagation path between Mauna Loa (Island of Hawaii) and Haleakala (island of Maui) mountains, and a tactical-range (7 km) propagation path at University of Dayton's College Park Center building. Both testbeds includes three laser beacons operating at wavelengths 532nm, 1064nm, and 1550 nm and a set of three identical optical receiver systems with fast-framing IR cameras for simultaneous measurements of pupil and focal plane intensity distributions. These experiments were focused on measurement of key laser beam parameters such as intensity scintillations, and image wander and widening simultaneously at three different wavelengths.

The comparison of experimental results showed significant difference in physics of atmospheric turbulence impact on laser beam propagation over long and tactical range distances. The experimental data were also compared with wave optics numerical simulations.

8380-17, Session 5

Automation of Cn2 profile extraction from weather radar images

S. T. Fiorino, L. Burchett, M. Buchanan, Air Force Institute of Technology (United States)

A novel method for measuring the structure constant of the atmospheric turbulence on an arbitrary path has recently been demonstrated by the Air Force Institute of Technology (AFIT). This method provides a unique ability to remotely measure the intensity of turbulence, which is important for predicting beam spread, wander, and scintillation effects on High Energy Laser (HEL) propagation. The experimental development of the technique has produced a complicated and time consuming process for estimating Cn2. This paper presents a new software program which is being developed to automate the AFIT process. The program will incorporate regional National Weather Service NEXRAD weather data including temperature, pressure and humidity profiles, and radar reflectivity measurements over the path of interest. The geometry of the path will be interpreted in the context of the data grid produced by the radar system. The program uses the Radar Software Library (RSL) produced by the Tropical Rainfall Measuring Mission (TRMM) at the NASA/Goddard Flight Center. RSL provides support for nearly all formats of weather radar data. Due to variations in radar systems and measurement conditions, the RSL produces data grids that are not consistent in geometry or completeness. The Cn2 program will adapt to the varying geometries of each radar image. Automation of the process will allow for fast estimation of Cn2 with a goal of providing real time turbulence estimations.

8380-18, Session 5

Turbulence characterization and image processing data sets from a NATO RTO SET 165 trial in Dayton, OH, USA

M. Velluet, ONERA (France); M. A. Vorontsov, Univ. of Dayton (United States); R. L. Espinola, U.S. Army Night Vision & Electronic Sensors Directorate (United States); G. Marchi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); S. Nicolas, Forsvarets Forsknings Institute (Norway); J. Riker, Air Force Research Lab. (United States); P. B. W. Schwering, TNO Defence, Security and Safety (Netherlands)

The performance of Electo-Optics systems is degraded by atmospheric turbulence. Over a large propagation distance, at least several km near the ground, it is difficult to evaluate its impact because of the variability of the ground effects and also the number of physical phenomena which must be included. But in order to design high-performance EO systems, the turbulence along the propagation path must be known along with its effects. This understanding is one of the main objectives of the NATO group SET 165: "Adaptive Optics for laser beam delivery, passive and active imaging and turbulence mitigation". An atmospheric trial was conducted in October 2011 in order to collect relevant data, using the optical benches and infrastructure on the University of Dayton site. Here we describe the experiment, the recorded data and how they are used. First results will be presented.

8380-19, Session 5

The measurement and remediation of coude path turbulence at the Starfire Optical Range Auxiliary Beam Director

M. Shoemake, A. C. Slavin, Boeing-SVS, Inc. (United States); R. L. Johnson, Air Force Research Lab. (United States)

Poor seeing along the Auxiliary Beam Director (ABD) path at the Starfire Optical Range (SOR) has been observed over the last decade. We describe an investigation of the causes of the path turbulence inside the ABD, the remediation we undertook, and the results of that remediation. The ABD path consistently measures a Fried parameter (r0) ranging from 2cm-3cm, while other instrumentation at the SOR indicates a simultaneous measured 6cm-7cm r0. Two telescopes were placed at different points along the ABD path, each measuring r0 using a Modulation Transfer Function (MTF). In addition, air temperature probes were also installed along the path, combined with thermocouples for mirror temperature measurements. We used these measurements to score the effects of various changes in the path, such as plugging air leaks. In this report we quantify the effects of these changes on the observed ABD path turbulence.

8380-20, Session 5

The statistics of the temporal variation of r0

E. J. Spillar, Air Force Research Lab. (United States); D. L. Fried, Consultant (United States); M. Shoemake, Boeing-SVS, Inc. (United States)

We use data from the SOR atmospheric monitor (SAM) to estimate the statistics of variation of the Fried parameter on timescales from milliseconds to hours. The SOR atmospheric monitor is a Shack Hartmann wave front sensor behind a 40 cm telescope which samples the wavefront from stars both day and night on a 2cm scale.

On the shortest scales we consider a quantity we call the instantaneous Fried parameter, or r0i, the best estimate of the quantity obtained from the wavefront distortions obtained during a single frame of data. We

are concerned with statistically significant changes in this quantity over timescales of milliseconds, since short bursts of statistically unlikely bad wavefronts might be the occasion of fades in adaptive optics systems.

Conversely, short bursts of statistically unlikely good wavefronts might be advantageous for lucky imaging.

On longer timescales, the statistics of seeing variation might be useful in scheduling observations which might require lengths of good seeing.

Relatively little rapid (millisecond) variation is observed, however significant variation is sometimes seen on time scales of seconds.

We characterize the variation in the strength of turbulence primarily through the mean square difference in the instantaneous Fried parameter in samples separated by given time intervals, that's the temporal structure function of the instantaneous Fried parameter.

8380-21, Session 5

Propagation of laser light through aero-optic flow: dry air at 0.4 Mach with three-dimensional turret

R. L. Beauchamp, Air Force Institute of Technology (United States)

A study is underway to address the effects of aero-optic (AO) flow components added to the typically modeled clean, dry AO flow over two-dimensional turret models. This is the first of multiple runs that will address effects of three-dimensional turrets, moist air and aerosols within a specific context. That context is for a turret in an airflow at 0.4 Mach with parameters matching atmosphere at 1 km. The turret dimensions are comparable that of an ongoing AO data collection experiment. This solution and the resulting analysis will be used as a baseline for comparison with airflow with the same parameters but including moisture, and again airflow that includes a realistic population of aerosol particles of varying size. Moisture inclusion will result in droplet formation in low pressure areas, altering local thermodynamics in the areas of droplet formation which will, in turn, affect air flow density and refractivity. The presence of droplets and aerosols will affect air flow by introducing scattering effects using energy from the flow for their transport. Water droplets will form on water soluble aerosol particles given a local drop in pressure and the presence of an appropriate amount of moisture. Aerosols are expected to affect scattering. All changes in density, airflow energy, absorption and scattering due to these additions will affect the optical path length (OPL) through the AO flow. Atmospheric properties were determined using High Energy Laser End-to-End Operational Simulation (HELEEOS).

8380-22, Session 6

The phase Strehl cumulative distribution function (cdf) in the performance modeling of adaptive optics systems

T. C. Farrell, U.S. Air Force (United States)

The role of phase Strehl (as a random variable) in adaptive optics performance modeling is discussed. The characteristic function, general form of the cdf, and results for two and three degrees of freedom are presented.

8380-24, Session 6

The aggregate behavior of branch points: verification in wave optical simulation I

D. W. Oesch, SAIC (United States); C. M. Tewksbury-Christle, D. J. Sanchez, P. R. Kelly, Air Force Research Lab. (United States)

Atmospheric turbulence imparts phase distortions on propagating optical waves. These distortions couple into amplitude fluctuations at the pupil of a telescope, which, for strong enough phase distortions, produce branch points (zeros in the amplitude). In our earlier work we have presented the case that branch points can be utilized as a source of information on the turbulent atmosphere. Using our bench-top data, we have demonstrated several properties of branch points including motion, density, persistence and separation. We have identifed empirical relationships for density and separation as functions of the strength and altitude for a single layer. However, this work was done using a bench-top adaptive optics system utilizing a two-layer atmospheric turbulence simulator. In this first paper, we use independently anchored wave optics simulations to verify these results. This simulation provides a means to further examine how the turbulence conditions contribute to the branch point distribution. Additionally, we look at the role of the inner scale in the formation of branch points within the optical simulation.

8380-25, Session 6

Theoretical justification for branch point velocity and invariance under a two layer atmosphere

D. J. Sanchez, Air Force Research Lab. (United States); D. W. Oesch, SAIC (United States)

In optical waves propagating through turbulence, branch points are created when the wave self-interferes to create a null in amplitude. Our previous experimental work has shown that branch points have velocity, that this velocity is directly related to the turbulence layer that created them, and that this velocity persists after propagation through additional layers. Here, we show that branch point velocity can be theoretically explained using the Fresnel propagator. We also show, for a range of conditions, why this velocity persists through multiple turbulence layers.

8380-26, Session 6

High-energy laser multivariable linear-regression performance modeling for surface-to-surface engagements

C. L. Leakeas, S. R. Capehart, R. J. Bartell, S. J. Cusumano, Air Force Institute of Technology (United States); M. R. Whiteley, MZA Associates Corp. (United States)

This paper discusses and demonstrates the use of multivariable linear regression techniques on data generated from many wave-optics simulations of surface-to-surface engagements for the development of High Energy Laser (HEL) performance models for a system of tiled subapertures. HEL performance models are a convenient way of developing a Tactical Decision Aid (TDA) for the warfighter. The use of a TDA will allow the warfighter two important measures of uncertainty in the surface-to-surface engagement: 1) the ability to predict the future point estimate of the dwell time and the associated 50% and 95% prediction intervals needed to deliver a prescribed amount of fluence of the HEL beam to the target, and 2) information by way of 95% confidence intervals on the mean value and 95% prediction intervals on the future point estimate of the HEL power-in-the-bucket (PIB) delivered to the target as a function of the thermal blooming distortion number (Nd) and the strength of the atmospheric turbulence (Cn2). Inputs to the performance model include the aperture phase errors, atmospheric turbulence conditions, thermal blooming, and other engagement parameters. The output of the performance model is the power-in-the-bucket where the bucket size is defined as the vacuum diffraction-limited spot diameter. Two HEL performance models are developed to demonstrate the robustness of a general performance model against a restricted performance model for a specific engagement of interest for surface-to-surface scenarios. Performance model development has shown that there is only limited performance benefit for fully coherent verses fully incoherent cases when no adaptive optics is used in the surface-to-surface engagement scenarios.

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8380-27, Session 6

Using Maple and special functions to study the propagation of coherent light beams inside the Earth's ionosphere waveguide with turbulent media

S. Montoya, Univ. EAFIT (Colombia)

Some special functions of the Mathematical Physics are a very helpful resource in problems involving the propagation of coherent light beams, which will suffer dispersion in a turbulent media such as the Earth's ionosphere waveguide. Unfortunately, these tools are difficult to use because it involves very complex mathematical developments. For this reason it is interesting to find a friendly method to make the implementation of these special functions possible. Using Maple I will be able to overcome the mathematical difficulty of solving these equations and get to the understanding of these phenomena. Specifically I will consider the excitation of the Earth's ionosphere as a cavity or a waveguide by satellite borne current sources in the form of satellite-based antennas when the medium inside the waveguide is turbulent. As a result, three kinds of coherent light beams will be derived: Bessel beams, for relatively low turbulence, Whittaker beams, for moderate turbulence, and Heun beams, for strong or fully developed turbulence. These beams are represented by the corresponding electric fields but the associated magnetic fields can be derived as well. It is verified that Maple is a very powerful tool in the study of the propagation of an input field through axially symmetric systems using the methods of the Mathematical Physics. It is expected that Maple will have important applications for more general models concerning propagation trough turbulent environments.

8380-28, Session 7

The mitigation of cloud impacts on free-space optical communications

R. J. Alliss, B. D. Felton, M. Mason, Northrop Grumman Corp. (United States)

The mitigation of clouds is a key driver in the performance of free space optical communication (FSOC) systems. Clouds are composed of liquid water and/or ice crystals and depending on the physical thickness can produce atmospheric fades easily exceeding 10 dB. In these more common cases, impacts on FSOC systems may be severe. On the other hand, there are times when cloud fades may be as low as 1 or 2 dB as a result of thin, ice crystal based cirrus clouds. In these cases, the impacts on FSOC communication collectors may be limited.

The ability to characterize the distribution and frequency of clouds are critical in order to understand and predict atmospheric impacts. A cloud detection system has been developed and applied to produce high resolution climatologies in order to investigate these impacts. The cloud detection system uses geostationary, multi-spectral satellite imagery at horizontal resolutions up to one kilometer and temporal resolutions up to fifteen minutes. Multi-spectral imagery from the visible wavelengths through the longwave infrared is used to produce individual cloud tests which are combined to produce a composite cloud analysis. The result represents a high spatial and temporal resolution climatology that can be used to derive accurate Cloud Free Line of Sight (CFLOS) statistics in order to quantify atmospheric effects on optical communication systems.

The Lasercom Network Optimization Tool (LNOT) is used along with a mission CONOPS and the cloud database to find configuration of geographically diverse ground sites which provide a high availability system.

8380-29, Session 7

Potential impacts of elevated aerosol levels on high-energy laser aerial-defense engagements

S. T. Fiorino, S. Shirey, M. Via, D. Grahn, M. J. Krizo, Air Force Institute of Technology (United States)

This study quantifies the impacts on high energy laser (HEL) air defense performance due to atmospheric effects in the atmospheric boundary layer driven by varying aerosol levels. The simulations are run using several different engagement geometries to more completely show the effects of aerosols. High adaptive optics are applied to reduce the turbulence effects. The atmospheric effects are defined using the worldwide probabilistic climatic database available in the High Energy Laser End-to-End Operational Simulation (HELEEOS) model. The anticipated effects on HEL propagation performance is assessed at 1.0642 µm across the world's oceans, mapped on a 1° x 1° grid, and at 573 land sites. The scenarios evaluated are primarily near-surface and horizontal over ranges up to 10000 meters. Seasonal and boundary layer variations (summer and winter) for a range of relative humidity percentile conditions are considered. In addition to realistic vertical profiles of molecular and aerosol absorption and scattering, correlated optical turbulence profiles in probabilistic (percentile) format are used. Results indicate profound effects of elevated aerosol layers on HEL engagements as compared to standard scenarios without elevated layers. Also, results suggest changing optical properties to have additional significant effects. HELEEOS characterizes aerosol environments using the Advanced Navy Aerosol Model (ANAM) or various representations of particulates from the Global Aerosol Dataset (GADS). In the lowest 50 m, HELEEOS defines optical turbulence with the Navy Surface Layer Optical Turbulence (NSLOT) model.

8380-30, Session 7

Assimilation of nontraditional datasets to improve atmospheric compensation

M. A. Kelly, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Detection and characterization of space objects requires the capability to characterize their physical properties such as brightness temperature and reflectance. These quantities, together with trajectory and position, are often used to correlate an object from a catalogue of known objects. However, retrieval of these physical quantities can be hampered by the radiative obscuration of the atmosphere. Atmospheric compensation must therefore be applied to remove the radiative signature of the atmosphere from EO collections and enable precise object characterization and typing.

The JHU/APL Atmospheric Compensation System (ACS) was designed to perform atmospheric compensation for long, slant-range paths at wavelengths from the visible to infrared. Atmospheric compensation is critically important for air- and ground-based sensors collecting at low elevations near the Earth's limb. Our results demonstrate that undetected thin, sub-visual cirrus clouds in the line of sight (LOS) can alter the transmittance along the line of sight by more than 50%. Our research uses non-traditional cirrus and water vapor datasets to account for small-scale variability in atmospheric radiative effects. We plan to discuss the algorithm and present results from recent collections.

8380-31, Session 7

Atmospheric propagation properties of various laser systems

G. A. Pitz, Air Force Research Lab. (United States); S. Glass, Haverford College (United States); B. Kamer, Air Force Research Lab. (United States); W. Klennert, Boeing-SVS, Inc. (United States); D. A. Hostutler, Air Force Research Lab. (United States)

Atmospheric propagation properties of various laser systems, including diode pumped alkali lasers (DPALs) and the Chemical Oxygen Iodine Laser (COIL), are of importance. However, there appears to be a lack of highly accurate transmission characteristics of these systems associated with their operating conditions. In this study laser propagation of the rubidium-based DPAL and the COIL has been simulated utilizing integrated cavity output spectroscopy. This technique allowed for the simulation of laser propagation approaching distances of 3 kilometers on a test stand only 35 cm long. The spectral output from these simulations was compared to the HITRAN database with extremely high agreement. The proximity of the laser line to the atmospheric absorbers is shown as well as the spectral profile of the beam at various pressures. This profile was then extrapolated using an in-house hyperfine model. These models allowed for the comparison of proposed systems and their output spectral profile. The diode pumped rubidium laser at pressures under an atmosphere has been shown to interact with only one water absorption feature, but at pressures approaching seven atmospheres the D1 transition may interact with more than 6 water lines depending on resonator considerations. Additionally, a low pressure system may have some slight control of the overlap of the output profile with the water line by changing the buffer gases.

8380-32, Poster Session

Detection probability of non-diffracting Bessel beams propagation in a slant atmospheric communication channel

Y. Zhang, Jiangnan Univ. (China)

The effects of turbulence have been investigated both theoretically and experimentally over the past few decades in the case of classical optics. In some cases, however, quantum effects may turn out to be significant. Their role increases in the case of a low power photonic sensing system that can perform single-photon detection, inverse imaging and single-photon communication. The purpose of this paper is to study the turbulent effects of atmosphere on the statistics of the detected photons which are generated by individual pulses of the diffraction-free beam propagating through the earth's atmosphere. Based on the assumption of a pulse laser beam with an initial Gaussian temporal shape of the pulse and diffraction-free -model spatial distribution, the Rytov approximation for solving the stochastic Helmholtz equation, the square approximation for the structure function of wavefront distortion and non-Kolmogorov (von-Karman type) spectrum model of the index-of-refraction fluctuation of atmospheric turbulence, the effect of turbulence on the detection probability of single-photon propagation in atmospheric communication channel is studied theoretically. The time duration broadening model of a initial Gaussian temporal shape pulse beam and the detection probability of the pulse and diffraction-free photon beam propagation in weak and slant path turbulent communication channel are developed. Our results shown that the transmittance probability densities of single-photon diffraction-free beam are decreasing as the structure constant of the fluctuation of the index of refraction and the propagation path increasing, but the transmittance probability densities are decreasing as the pulse broadening increasing.

8380-33, Poster Session

USAF high-energy laser (HEL) systems: HEL-generated extinction effects and degradation of multispectral algorithm efficiencies during missile staging (case PRC DF-31; GHADR 110)

C. A. Paiva, H. S. Slusher, BSM Research Associates (United States)

USAF High Energy Laser (HEL) Systems: HEL-Generated Extinction Effects and Degradation of Multi-Spectral Algorithm Efficiencies During Missile Staging (Case PRC DF-31; GHADR 110)

This comprises continued research addressing missile exhaust plume ionization adverse effects; such HEL ionization processes occurring as a function of altitude, exhaust plume expansion, reverse exhaust flow. It is demonstrated that these processes adversely affect the USAF multi-wavelength Discriminating Interceptor Technology Program (DIT)'s infrared and millimeter wave fused system. Target case study are the PRC DONG FENG 31 solid propellant systems, with applications to Iranian GHADR 110 MRBM (extended). Boost-phase missile exhaust plumes have been shown to generate a variety of very challenging exhaust-plasma and electromagnetic HEL extinction effects. As a result the HEL fluence (energy in the bucket), decreases in intensity. The overall engagement event results in HEL plasma-plume interactions (absorption-scattering) reducing returned energy on the infrared focal plane for HEL designators; and reduced HEL fluence on target. Application: plasma/HEL/IR interactions generate a reduction of coherence of the detection the target ATDCI (automatic target detection, classification and identification) components and the primary HEL weapon system (USAF Airborne Laser). Video analysis included 10 July 2011 Chinese launch of DF-31, from which exhaust plume spatial and temporal characteristics were obtained. Such missile discriminates included expanded and reversed exhaust plumes, which are shown to generate very severe propagation extinction within the Prandtl-Meyer and HEL engagement regimes. This further results in inadequate automatic target recognition and effective pattern reference libraries. Unique HEL plasma-plume interactions occur when asymmetric flows interact with high-energy laser transmissions through missile Prandtl-Meyer reverse flow regions and high angle-of-attack regimes. Angle-of-attack asymmetric radiance increases result from increased trajectory energy maintenance maneuvers by boost-phase missile exhaust, including dedicated energy maneuvering and evasive thrust vectoring. Intense exhaust plume/atmospheric ram interactions result in high critical ionization levels within the missile chemical excitation regions which then interact with HEL designator and primary beams. Cumulatively these processes challenge ATDCI algorithms, which rely on ATDCI-ATR (automatic target recognition) referencing systems. Current ATR algorithms do not account for these negative plasma-plasma interactions of asymmetric, angle-of-attack rocket exhausts and high-energy laser plasma interactions. ADTCI-ATR libraries must include sufficiently robust exhaust plasma data to insure high probability of successful target intercepts. Finally, these libraries must include angle-of-attack and afterburning characterizations for the new boost-phase Iranian: GHADR-110, PRC DF-31, and North Korean TAEPODONG-2/III ICBM missile systems which are in production.

8380-34, Poster Session

Mobile free-space optical communications: a feasibility study of various battlefield scenarios

A. Harris, Univ. of North Florida (United States); M. K. Al-Akkoumi, J. J. Sluss, Jr., The Univ. of Oklahoma - Tulsa (United States)

Free Space Optics (FSO) technology was originally envisioned to be a viable solution for the provision of high bandwidth optical connectivity in the last mile of today's telecommunications infrastructure. Due to atmospheric limitations inherent to FSO technology, FSO is now widely envisioned as a solution for the provision of high bandwidth, temporary mobile communications links. The need for FSO communications links will increase as mobility is introduced to this technology. In this paper, a theoretical solution for adding mobility to FSO communication links is introduced. Three-dimensional power estimation studies are presented to represent mobile FSO transmission under various weather conditions. Three wavelengths, 0.85, 1.55 and 10 um, are tested and compared to illustrate the pros and cons of each source wavelength used for transmission, depending on prevalent weather conditions and atmospheric turbulence conditions. Various battlefield situations involving mobile platforms are investigated in order to determine the feasibility of establishing and maintaining an operations FSO communication link. A simulation analysis of the transmission properties of the source wavelengths used in the study will be presented.

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8381-01, Session 1

Glass-clad single crystalline fiber lasers

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Yttrium aluminium garnet (YAG) has been widely used as a high power solid-state laser host because of its superior optical, thermal, mechanical properties, as well as its plurality in hosting active ions with a wide range of ionic radii. Drawing YAG into single crystalline fiber has the potential to further scale up the attainable power level with high mode quality. The recent advancement on the codrawing laser-heated pedestal growth (CDLHPG) technique can produce glass-clad YAG fibers for laser and optical amplifier applications. The drawing speed can reach 10 cm/min for mass production. With core pumping scheme, the CDLHPG technique has shown advantages on transition-metal ion doped YAG and short-fluorescent-lifetime ion doped YAG for low-power applications. Compared to silica fiber lasers, the crystalline core offers high emission cross section for transition metal ions because of the unique local matrix. With clad-pump scheme, glass-clad YAG fiber may be suitable to scale up the damage threshold of moderate to high power lasers with narrow linewidth for rare earth dopants.

The challenges on the development of glass-clad YAG fibers, including core crystallinity, diameter uniformity, dopant segregation, residual strain, post-growth thermal treatment, and the thermal expansion coefficient mismatch between the crystalline core and glass clad, will be addressed in the presentation. Chromium, ytterbium, and neodymium ions doped YAG fiber lasers have been successfully achieved with high efficiency and low threshold powers. Power scaling with clad-pump/side-pump schemes using single clad or double clad YAG fibers will also be discussed.

8381-02, Session 1

Mode-converters for rectangular-core fiber amplifiers to achieve diffraction-limited power scaling

A. K. Sridharan, P. H. Pax, J. E. Heebner, D. R. Drachenberg, J. W. Dawson, Lawrence Livermore National Lab. (United States)

Ytterbium doped fiber lasers and amplifiers at 1 um (based on circularly-symmetric waveguides) that routinely output ~ 10 kWs with diffraction-limited beam quality are approaching fundamental limits. By moving to ribbon-like rectangular-core fiber waveguides, the single aperture power limit of circular core fiber lasers is increased. The ribbon fiber waveguide has a rectangular cross-sectional core with a high width-to-thickness aspect ratio. In such a structure the thin dimension (y) is coiled and single-moded and the wide dimension (x) is multi-moded. Since higher-order-modes (HOM) are less susceptible to bend loss and mode mixing we propose ribbon fiber amplifiers in which we launch a particular HOM (in the x direction). Mode-converters are therefore required before and after the ribbon-amplifier fiber.

We present the first design and experimental results of a mode-converter system that converts a typical laser's output TEM00 mode to a single HOM of a ribbon-geometry-based amplifier fiber. Our work builds on Leger's approach (which utilizes two phase plates - placed in two conjugate Fourier planes of the laser's output face) and has nearly 100% theoretical conversion efficiency. The first plate splits the input Gaussian profile to the ribbon fiber's multi-lobed HOM amplitude profile in the plane of the second plate. The second phase plate corrects the phase that is present in that plane and as a result we achieve the required HOM amplitude and phase. We also present designs on how to apply this scheme to improve the beam quality of a circular-core fiber that outputs radiation in a single HOM.

8381-03, Session 1

Fabrication and properties of Ho-doped silica core fibers for high-energy laser applications

E. J. Friebele, C. G. Askins, J. R. Peele, S. R. Bowman, N. J. Condon, S. P. O'Connor, U.S. Naval Research Lab. (United States)

Ho-doped fiber lasers (HoDFLs) are attractive for high energy laser (HEL) applications because of their 90% theoretical efficiency, potential for power scaling, and the fact that they can be made to operate near 2.1 microns to take advantage of being in the eye-safer wavelength range >1.4 microns in a window of low atmospheric absorption. Because of the long operating wavelength, materials issues arise that are not relevant for Tm- or Er-doped high energy lasers but are critical to efficient performance of HoDFLs and operation at high power. These include reducing the OH concentration to minimize absorption of the laser since the fundamental vibrational band of OH is at 2.75 microns with a combination band at 2.2 microns. Laser modeling has shown that the [OH] must be <1 ppm for good performance. We will describe how this was achieved using ultra-dry reagents, a new in-situ solution doping process, and extensive drying. A second issue is eliminating polymer coatings to avoid absorption of the high power pumps and resultant heating; we address this through the use of air claddings for the pump. Finally, multiphonon quenching must be minimized through the substitution of higher molecular weight ligands for the oxygen ions typically found in oxide glasses. This paper will report progress towards addressing these issues and the results of modeling fiber laser performance using the best achieved results.

8381-04, Session 1

Modal properties of photonic crystal fiber for high-power two micron fiber laser systems

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Interest in coherent light sources emitting in the 2 micron wavelength range has dramatically increased in the past years. Efforts for developing such sources are motivated by a large variety of applications, from spectroscopy and component testing to atmospheric sensing, from eye-safe LIDAR to directed energy applications. Fiber lasers and amplifiers with Tm and Ho as active rare earth ions show great promise for efficient, reliable and cost effective light sources in the 2 micron range. For applications that require scaling up optical powers and pulse energies of fiber lasers optical fiber that support single mode operations while achieving large mode areas are needed. In addition, active and passive versions of such fiber have to be matched to enable the construction of lasers, amplifier as well as high power delivery systems.

Here we report on a study of the modal properties of a new-generation of polarizing large-mode-area photonic crystal fibers based on the spectrally and spatially resolved (S^2) imaging technique. Active and passive fibers suitable to build Tm fiber lasers have been designed and fabricated by NKT Photonics. For fibers with >1000 square microns mode field areas robust single mode operation in the 2 micron spectral range is demonstrated for coiling diameters smaller than 40cm. At shorter wavelengths in the 1.3 micron range, efficient higher order mode suppression requires tide coiling to about 10cm diameters.

8381-05, Session 1

Mode area scaling for high-power fiber lasers with all solid photonic bandgap fibers

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There are very strong interests for power scaling in high power fiber lasers for a wide range of applications in medical, industry, defense and science. In many of these lasers, fiber nonlinearities are the main limits to further scaling. Although numerous specific techniques have studied for the suppression of the wide range of nonlinearities, the fundamental solution is scaling mode areas in fibers while maintaining sufficient single mode operation. Here the key problem is that the fundamental physics states more modes are supported once physical dimensions of waveguides are increased. There are two fundamentally different approaches, lower refractive index contrast to counter the increase of waveguide dimension or/and introduction of additional losses to suppress higher order mode propagations. Lower index contrast leads to weak waveguides, resulting in fibers no longer being coil-able. Our research has been focused on designs for significant higher mode suppression. In conventional waveguides based on total internal reflections, modes are increasingly guided in the center of the waveguides when waveguide dimensions are increased. It is hard to couple modes out to create modal loss. This severely limits the scalability of all designs based conventional waveguides. In an all solid Photonic bandgap fiber, modes are guided due to anti-resonance of cladding photonic crystal lattice. This leads strongly mode-dependent guidance. Our theoretical study has shown that it has the highest differential mode losses among all known designs with equivalent mode areas. We have fabricated fibers with ~55micron core diameters. Our preliminary experimental results confirm our theoretical study.

8381-06, Session 1

Depressed cladding architecture for waveguide lasers fabricated by femtosecond pulses in crystals

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NIR femtosecond laser beam tightly focused to a waist of elliptical cross section with strong ellipticity is an effective tool for inscribing of smooth tracks of modified crystal body with reduced refractive index. Such a track is an elementary unit for fabrication of depressed cladding waveguides (DCW). We investigated waveguides formed in rare earth doped YAG and RbPb2Cl5 crystals, when cladding consists of an array of tracks forming a tube, while core is intact domain of crystal. DCWs written in YAG:Nd crystals possess record low propagation loss among other waveguides fabricated by femtosecond pulses.

DCW is a basis for compact and efficient CW microchip lasers suitable for pumping by low cost laser diode. The waveguide laser and the laser diode are directly coupled by multimode fiber without lenses used for this purpose in solid state lasers. DCW was written in diffusion bonded YAG:Cr4+/YAG:Nd crystals serving as a basis for a microchip waveguide Q-switch laser with sub-nanosecond pulse duration. The waveguide confines both lasing mode and pump emission, thus the waveguide microchip laser has factor of 3 higher efficiency than a bulk microchip laser with the same output pulse energy and duration. So as in a waveguide laser mode profile is controlled by refractive index profile in contrary to bulk microchip laser, where mode size is defined by thermal lens induced by pump, microchip laser based on DCW has output pulse parameters independent upon repetition rate.

A DCW technology has shown to be feasible in low phonon Dy:RbPb2Cl5 crystal. It is promising for fabrication of waveguide lasers operating in mid-IR. However depressed cladding architecture should be further developed for mid-IR so as wavelength is considerably larger than track thickness, and clad geometry like a photonic crystal fiber is required in order to suppress mode leakage.

8381-07, Session 2

Advanced smart multifunctional laser crystals for next generation solid state lasers

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Single crystals containing multifunctionalities can address many of the factors that limit the performance of solid-state lasers. When combined with crystal joining technologies, new crystal functionalities emerge that can further improve solid-state laser performance; we refer to this new generation of laser crystals as “smart”. We report on the growth of crystalline structures using a variation of hydrothermal epitaxial growth that enables reduced thermally-induced beam distortion, and the suppression of amplified spontaneous emission (ASE) and parasitic oscillations. Crystals are grown as high quality monolithic single crystals with single or multiple ion doping. Additional layers can then be grown (around a barrel or at a disk edge for example) that provide ASE and parasitic suppression in one zone, an un-doped layer in two end zones that provide resistance to thermally-induced strain end-face distortion. Additional zones can be incorporated to provide a doping gradient to achieve uniform pump power deposition in end-pumped lasers. As an example of our approach, we will present results on the growth of YAG single crystals incorporating Nd3+ as the lasing ion and Cr4+ as the saturable Q-switch, and Sm:YAG grown on the barrel of the crystal to suppress ASE at 1064 nm. We will also discuss new smart crystal designs that are designed to work as end or side-pumped rods, thin and thick disks, and slabs that incorporate ASE suppression. In addition, we will present smart laser structures that incorporate methods to suppress thermal focusing by the incorporation of negative dn/dT materials. Our emphasis at present is on cubic materials such as YAG, LuAG, and Y2O3 incorporating Yb and Nd as lasing ions.

8381-08, Session 2

Alternative wavelengths for optically pumped alkali lasers

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As pump intensity in Diode Pumped Alkali Lasers (DPAL) is scaled to more than 100 times threshold, several nonlinear optical processes are encountered including two photon absorption and stimulated Raman scattering. A pulsed, optically pumped potassium laser with pump intensities exceeding 1 MW/cm2 has been demonstrated with output intensities exceeding 100 kW/cm2, requiring helium buffer gas pressures above 3 atm. At low pressure Stimulated Elecronic Raman Scattering (SERS) has been observed in the same system. When a potassium vapor cell surrounded by a stable cavity is pumped with a pulsed dye laser near the 42P resonances, Stokes and anti-Stokes lasing due to Stimulated Electronic Raman Scattering (SERS) is generated. When the pump is tuned about halfway between the ne structure levels of the 42P state, an ecient hyper-Raman process dominates, resulting in tunable laser radiation near 769 nm with a slope eciency of about 10.4%.

Up to 12 mW of red light is produced at a pump input of 232 mW. The threshold for the hyper-Raman process is about 60 mW. Two-photon absorption at wavelengths near then DPAL pump transition has also been observed and used to demonstrate lasing in the blue and mid infrared. Lasing in the blue has also been achieved by direct excitation of the second excited 2P3/2 level in Cs.

8381-09, Session 2

Diode pumped alkali laser kinetics: comparison of theory and experiment

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The performance of Diode Pumped Alkali Lasers (DPAL) depends critically on both collisionally broadened linehapes and rates for fine structure mixing. The database associated with these processes will be reviewed. The first four potential surfaces for K, Rb, and Cs interactions with rare gases have been computed at the MCSCF/MR SOCI level. These surfaces are then used to compute absorption lineshapes and scattering matrix elements for the spin-orbit relaxation, yielding temperature dependent cross-sections. Theoretical predictions are compared to recent experimental results. The observed fine structure mixing rates for rare gas collisions are interpreted in terms of collision adiabaticity. For molecular partners, ro-vibrational energy appears to dominate the mechanism. The impact of the rates on laser device performance will be discussed using recently reported analytic laser models. Finally, recommendations for further development of the fundamental parameters associated with DPAL systems will be presented.

8381-10, Session 3

Crystalline fibers for the middle infrared

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Middle-infrared optical crystals of metal (K, Cs, Ag) halides (Cl, Br, I) and their solid solutions have cubic rock-salt structure, lowest phonon energy of 100-130 cm-1 and lowest multi phonon absorption in the middle infrared 5-15 µm. Silver halide single crystals of solid solutions AgClxBr1-x (where 0< x< 1) have a wide infrared transmission window 1 - 20 µm and unique combination of non-hygroscopic nature and excellent mechanical properties. Fabrication of low losses crystalline fibers from these materials is a great challenge in advanced optical material technology. Silver halides are used for fabrication of multimode and single mode core-clad step index and micro structured fibers by extrusion technique.

We report extrusion of crystalline fibers with lowest fundamental losses 0.04 dB/m in 7-12 µm region.

8381-11, Session 3

High-power quantum cascade lasers and laser arrays

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The latest results on high power quantum cascade lasers (QCLs) at Adtech will be presented in this talk. High power single-emitter performance in the mid-wave IR (MWIR, lambda=3-5um) and long-wave IR (LWIR, lambda=8-12um) spectral ranges will be reviewed and compared. Challenges in output power, efficiency and power scaling will be presented and the investigated approaches and solutions adopted will be shown by comparing different results in the very broad wavelength range covered by QCL technology. Single-emitter continuous powers in the Watt range at room temperature have been achieved at both MWIR and LWIR wavelengths, serving different applications. Power scaling approaches will also be discussed by showing results on QCL arrays including multiple-emitter geometries and high power QCL minibars installed on high power heat sinks. Multi-emitter bars mounted on CS-type submounts have been tested for pulsed operation at different duty cycles at room temperature. Maximum power outputs in the P=5-10W range have been demonstrated for wavelengths in the MWIR range, while total powers below P=5W are attained in the LWIR range, due to the reduced electro-optical conversion efficiency at longer wavelengths. Potential power and efficiency improvements and mechanisms for beam combination will also be discussed.

8381-12, Session 3

Correlation of mid-infrared quantum cascade laser performance with laser design parameters

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We have developed a number of different quantum-cascade (QC) laser designs spanning the wavelength range between 3.8 and 5.3 microns. The active regions of these designs consist of strained layers of (In,Ga)As and (In,Al)As. For several of these designs, we have varied design parameters including injector doping, section-coupling strength, and the number of QC laser periods. We have grown InP-top-clad QC lasers from these designs using combined MBE/MOCVD growth, and we have fabricated 4-mm-cavity-length ridge lasers from this material, with ridge widths between 7 and 11 microns. The lasers have thick electroplated gold “thermal blankets” and are mounted epi-side-down on AlN submounts. Lasers were tested near room temperature under both cw and quasi-cw conditions. In this presentation, we will describe and compare the performance of the various lasers, and we will correlate their performances to the variations used in their designs.

8381-13, Session 3

Tunable mid-infrared generation using a synchronized programmable fiber laser

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Mid-infrared (MIR) lasers find interesting applications in laser-based countermeasure technologies, remote sensing, maritime/terrestrial awareness and so on. However, the development of laser sources in this spectral region is limited.

We present here an alternative solution to the MIR lasers which are based on difference-frequency generation (DFG) in a nonlinear crystal pumped by synchronized and tunable near-infrared (NIR) fiber lasers that are commercially available. This idea is not new and has been explored by others, but the latest innovations in NIR fiber lasers have enabled the creation of fast-scanning picoseconds fiber lasers. One such picosecond system is the Synchronized Programmable Laser (SPL) that can combine two picosecond fiber laser systems in which both output pulses are synchronized at the DFG crystal.

The first laser was continuously tunable from 1525 nm to 1600 nm and one million different wavelengths can be scanned within one second. For the second fiber laser, its wavelength was fixed at 1080 nm. In principle, the DFG in a PPLN crystal could produce a wide tunable MIR source. Here, a MIR source spanning from 3.32 µm up to 3.7 µm will be considered. For such PPLN crystal, the DFG phase-matching window for a fixed temperature was 2.6 nm wide and was broad enough for our 25 ps pulse train having a spectral width of 0.25 nm. The quantum efficiency achieved for the DFG was 44%. The use of a chirped PPLN would allow much larger MIR tunability and very fast wavelength scanning at a fixed temperature of the chirped PPLN crystal.

8381-14, Session 3

Modeling of the type-II InGaAs/GaAsSb quantum well designs for mid-infrared laser diodes by k p method

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Different type-II structure InGaAs/GaAsSb quantum well design structures on InP substrate for mid-infrared emission has been modeled by six band k p method. The dispersion relations, optical matrix element, optical gain and spontaneous emission rate are calculated. The effects of the parameters of quantum wells (thickness, composition) and properties of cladding layers were investigated. For injected carrier concentration of 5×10^12 cm^-2, peak gain values around 2.6-2.7 μm wavelengths of the order of 1000 cm^-1 can be achieved, which shows that type-II InGaAs/GaAsSb quantum wells are suitable for the mid-infrared laser operation at room temperature.

8381-15, Session 4

Advancements in high-power diode laser stacks for defense applications

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High power diode lasers and diode-pumped solid-state lasers have secured their position in traditional defense applications such as target designators, rangefinders, illuminators and infra-red counter measures (IRCM). The diode laser, by virtue of its breadth of power and wavelength offerings, configurability, modularity, compactness, high efficiency and ability to operate under harsh environmental conditions lends itself very well to the demanding requirements of military and aerospace. In recent years, the escalating interest in directed energy laser weapons has once again put the diode laser and diode-pumped lasers as a key enabling technology to realize the goal of deploying laser weapons in combat.

This paper reports on the latest advancements in high-power diode laser stacks, which deliver the most compact footprint, power scalability and highest power/bar of any diode laser package. We present electro-optical (E-O) data on water-cooled (micro-channel) stacks with wavelengths ranging from 7xx nm to 9xx nm and power levels of up to 5.8kW, delivered @ 200W/bar, CW mode, and power-conversion efficiency of >60%, with both-axis collimation on a bar-to-bar pitch of 1.78mm. Also, presented is E-O data on a compact, conductively cooled, hard-soldered, stack package based on conventional CuW and AIN materials, with bar-to-bar pitch of 1.8mm, delivering average power/bar >15W operating up to 25% duty cycle, 10ms pulses @ 45C. The water-cooled stacks can be used as pump-sources for pumping diode-pumped alkali lasers (DPALs) or for more traditional DPSS lasers which are power/brightness scaled for directed energy weapons applications and the conductively-cooled stacks as illuminators.

8381-16, Session 4

High-brightness, frequency-stabilized diode laser at 1530nm

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We report on high brightness diode laser at 1.5 m with wavelength stabilized output. 30W are delivered from a 100 m fiber of 0.15 NA at 1532nm with a bandwidth of 2 nm. InP diode lasers emitting at 1.5 m show much lower power than GaAs based diodes emitting around 900 nm due to the low electro-optical efficiency of 1.5 um diodes of about 35%, compared to about 65% of GaAs diodes. Efficient heat dissipation from the diode is thus essential for power scaling at 1.5 m. Single emitters allow the highest power from given size broad area emitter due to optimized cooling. Up to 6W (15W) are available from a 95 m broad area single emitter at 1.5 m (9xx nm) with optimized cooling. At 1.5 m the maximum power is typically limited by thermal roll over. Optical stacking is deployed for power scaling thus symmetrizing the beam quality in fast and slow axis for efficient fiber coupling. We typically achieve 67% optical efficiency for optical stacking and fiber coupling resulting in more than 30W from a 100 m fiber of 0.15 NA.

Resonant pumping of Er lasers requires a 2nm linewidth at 1532nm. The free running diodes show about 7nm linewidth and about 2.5nm/A tuning coefficient with varying drive current depending on cooling specifics. Frequency stabilization is achieved with Volume Holographic Gratings (VHG) balancing locking range with power drop. >90% power are confined within a 2nm bandwidth over the whole drive current range with minimum power penalty.

8381-18, Session 5

High-power vertical-cavity surface-emitting lasers for diode pumped solid-state lasers

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Vertical-cavity surface-emitting lasers (VCSELs) present an attractive low-cost alternative as a high-power semiconductor laser pump source, because they can be easily processed in large two-dimensional (2-D) arrays of smaller single devices driven in parallel to scale up the power. These arrays can be furthered tiled together to generate even higher powers. These VCSEL arrays emit in a circular, uniform beam which can greatly reduce the complexity and cost of coupling optics. Their narrow and stable emission spectrum is well suited to the narrow absorption spectrum generally observed for solid-state gain media. The proven reliability of VCSELs greatly enhances the robustness of solid-state laser systems and enables high-temperature operation.

We will discuss recent developments on kW-class VCSEL pumps for solid-state lasers. Results on VCSEL modules designed for end-pumping and for side-pumping of Nd:YAG rods will be presented. Coupling is achieved via simple optics and in some cases the VCSEL pump can even be directly butt-coupled to the gain medium. We will also present results on frequency doubled (blue, green) and quadrupled (UV) lasers using VCSEL pumps. A VCSEL-array dual side-pumped Nd:YAG laser operating at 946 nm was actively Q-switched and frequency-doubled to generate 10mJ blue laser pulses. For another application a VCSEL-array end-pumped Nd:YAG laser operating at 1064 nm was passively Q-switched and frequency doubled to produce 10mJ green laser pulses. High-energy UV pulses were obtained by frequency doubling the green output.

8381-19, Session 5

Low SWaP semiconductor laser transmitter modules for ASCENDS mission applications

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NASA Langley Research Center, working with its partners, is developing fiber laser architecture based intensity modulated CW laser absorption spectrometer for measuring XCO2. In support of this measurement, sensor technology for remote sensing of O2 in the 1.26-1.27-μm band for surface pressure measurements is being developed. In this paper, we will present recent progress made in the development of advanced transmitter modules for CO2 and O2 sensing. A DFB laser transmitter module operating at 1571nm, incorporating a low-noise variable laser bias current supply and low-noise variable temperature control circuit, has been developed and extensively tested. These modules operate at

>80mW and could be tuned continuously over the wavelength range of 1569-1574nm at a rate of 2pm/mV. Fine tuning was demonstrated by adjusting the laser drive at a rate of 0.7pm/mV. Heterodyne linewidth measurements have been performed showing linewidth ~200kHz and frequency jitter ~75MHz. DFB laser transmitter modules operating at the absorption line of 1262nm have also been built and tested. We have shown continuous tuning over a range of 1261.4 - 1262.6nm by changing chip operating temperature and 1261.0 - 1262.0nm by changing the laser diode drive level. In addition we have created a new laser package configuration which has been shown to improve the TEC coefficient of performance by a factor of 5 and improved the overall efficiency of the laser transmitter module by a factor of 2.

8381-20, Session 5

Wavelength-stabilized, fiber-coupled, 975-nm diode-laser module with > 500 W output and 20 mm × mrad beam quality

D. M. Grasso, N. Shou, H. Chen, G. Cheung, R. Pathak, P. Liang, D. Lee, Coherent, Inc. (United States)

We report the development of a fiber-coupled diode laser module with high spatial and spectral brightness. Four arrays of diode laser bars are multiplexed using polarization and narrow-band wavelength combination. The module achieves 500 W of output power from a 200 µm, 0.2 NA fiber. The output spectrum, composed of contributions from more than 150 emitters, is narrowed using VBGs and has nearly 100% content within +/- 1 nm of 975 nm at full power. We will also discuss ongoing work to pump an active Yb-doped fiber.

8381-21, Session 5

Enhanced fiber coupled laser power and brightness for defense applications through tailored diode and thermal design

S. Patterson, T. Koenning, DILAS Diode Laser, Inc. (United States); B. Köhler, J. Biesenbach, DILAS Diodenlaser GmbH (Germany)

Advances in both diode laser design and packaging technology, particularly thermal management, are needed to enhance the brightness of fiber coupled diode lasers while maintaining the small size and light weight required for defense applications. The diode must be carefully designed to ensure not only high power but also efficient coupling of the energy into the fiber. Here thermal management plays a critical role in both increasing the output power per diode laser and controlling the slow axis divergence of the diode. In order to maintain small packages and light weight, tailored bars of 5 emitters are used, reducing the number and complexity of optics as well as the number of manufacturing steps required to build the modules. Careful development of heat sink design and mounting must be mastered for this approach to be successful. The principles of design for high efficiency fiber coupling will be covered in detail. Examples will be provided of fielded and demonstrated 100 and 200 micron diameter fiber coupled packages ranging in output from a few hundred to kW-class units in fibers, to include sub-kg/kW capabilities.

8381-22, Session 5

Brightness scaling of laser diodes at 9xx and 15xx nm

K. Price, L. Bao, J. Bai, Z. Chen, D. Dawson, M. DeVito, M. Kanskar, nLIGHT Corp. (United States)

We report on the development of high brightness broad area laser diodes at nLIGHT. We demonstrate that by optimizing the emitter width the brightness of diode lasers at 9xx nm can be increased by approximately 20%. Increasing cavity length to 5 mm provides an additional 15% improvement in device performance. These results are also demonstrated at 15xx nm useful for nighttime illumination and the resonant pumping of Er:YAG. We report on the limitations of power scaling of single emitter laser diodes due to device heating, longitudinal spatial hole burning, optical absorption, and carrier effects.

8381-23, Session 6

Recent developments in passive phase locking and combining of lasers

N. Davidson, A. A. Friesem, M. Nixon, Weizmann Institute of Science (Israel); M. Fridman, Cornell Univ. (United States); E. Ronen, Ben-Gurion Univ. of the Negev (Israel)

Some recent developments in phase locking and coherent combining of many lasers will be presented. We will describe methods where phase locked lasers serve as platforms for passive and efficient combining to obtain compact, stable, and practical laser configurations that can generate high output powers concomitantly with good output beam quality, as well as for investigating the dynamics of many coupled oscillators. The principles of the methods, the laser configurations, experimental procedures and recent results with solid state lasers and fiber lasers will be presented.

8381-24, Session 6

Coherent coupling of spectrally broadband laser channels

A. I. Khizhnyak, V. B. Markov, Advanced Systems & Technologies, Inc. (United States)

This presentation discusses the results of an analysis and experimental realization of a novel technique for an effective coherent combining of an array of spectrally broadband laser channels. The multi-channel coupling is performed in the stable laser cavity configuration and is applicable for any laser medium, including fiber, solid-state, semiconductor lasers. Coherent coupling of the individual channels uses the features of high index laser modes modeled by the matched spatial pattern of the sub-beams to be combined.

The spatial structure of such modes allows an efficient (up to 97%) coupling of the individual channels of an array to an intra-cavity high-index mode. It is essential that the proposed scheme enables automatic matching the spectral bands of a broadband spectral radiation. The latter, for example, suppresses nonlinear effects in the fiber channels. Since a high-index mode has a Pi-phase shift between adjacent sub-beams the proposed beam combining architecture can operate by using a straightforward steady-state phase corrector resulting in a diffraction limited output beam. This presentation discusses several examples of experimental realization of the coupling spectrally broadband channels, including effects associated with the selection and stabilization of the operating mode at minimal losses in oscillation efficiency

8381-25, Session 6

Coherent beam combining of single-mode fiber lasers using multiplexed volume Bragg gratings

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We present passive coherent beam combining of two- and four-channel single-mode fiber lasers using multiplexed volume Bragg gratings (MVBGs) recorded in PTR glass. Experimental study of two and four multiplexed (M2VBG and M4VBG) Bragg grating combiners is presented.

Four fiber laser channels are constructed using Yb-doped 6/125 PM fiber, core-pumped via a fiber WDM with a single-mode laser diode at 976 nm and 500 mW maximum power. The other end of the active fiber is spliced to an in-line fiber polarizer. A free-space half-wave plate is used in the external cavity to control the polarization orientation of the output beam. The optical lengths of the laser channels are not precisely equalized.

Two fiber lasers are coherently combined using a 2 channel reflecting M2VBG with an efficiency of >90%, diffraction-limited beam quality, and polarization extinction ratio >20 dB. The slope efficiency of the combined system is ~50% and the average output power is highly stable (standard deviation 70 dB. The effect of angle detuning the MVBG is discussed.

Longitudinal common-cavity modes of the combined system are studied for very narrowband (~10-50 pm) and broadband (> 200 pm) VBG combiners and correlated with combining efficiency. Power scalability using large mode area fibers and channel scalability using higher order VBG multiplexers are discussed.

8381-26, Session 6

High-efficiency, multilevel, diffractive optical elements for spectral beam combining

S. A. Kemme, D. W. Peters, D. A. Scrymgeour, Sandia National Labs. (United States)

We will present a broadband, all-dielectric, diffractive optical element (DOE) for spectral beam combining with optimized efficiency. We achieve maximal efficiency and polarization insensitivity by introducing multiple levels in the diffractive profile and a two-dimensional phase layout. Design and fabrication considerations that maximize efficiency are quantified, including material options, e-beam defined lithographic parameters such as grating duty-cycles and profiles, tailored wavelength dispersion, and polarization independence. These results will be compared to published efficiency values of >95% diffraction efficiency for a single polarization (Perry, Opt. Lett., 1995) and polarization-independent efficiency values of >98% (Wirth, Opt. Exp., 2009) over a limited range of angles and wavelengths.

This high-efficiency, multilevel DOE beam combiner addresses critical device technology for broadband illuminators, trackers, and chirped pulse compression. Moreover, the all-dielectric makeup ensures efficient and lightweight thermal management. Finally, the diffractive optical design can control aberrations, or add beam-shaping phase elements, with e-beam lithographically-defined features.

8381-27, Session 7

High average power-high peak power cryogenic Yb:YAG lasers for pumping Ti:Sapphire and OPCPA ultrafast lasers

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Ti:Sapphire and optical parametric chirped-pulse amplifier ultrafast laser systems are currently limited in average power to 0.5 J, and with a repetition rate up to 1 kHz. Yb based lasers are particularly promising because of a long upper state radiative lifetime, reducing the diode pump power needed to produce a target energy/pulse, as well as very favorable high average power scaling properties at liquid nitrogen temperature. A comparison of a number of Yb based materials including Yb:YAG, Yb:Lu2O3, and others will be presented. Using a recently developed kinetics model as well as a new system design model, we describe the average and peak power scaling of cryogenic Yb:YAG lasers as well as the limitations imposed by optically induced damage, nonlinear phase accumulation, and amplified spontaneous emission. The prospects for further scaling to 100 J/pulse and beyond will also be discussed.

8381-28, Session 7

High average power Yb:YLF cryogenic laser amplifier for subpicosecond pulses

D. E. Miller, MIT Lincoln Lab. (United States)

Cryogenically cooled Yb-doped YAG has proven to be an effective gain medium for scaling the average power of solid-state lasers to kilowatt levels while maintaining excellent beam quality. While cryogenic cooling enhances the thermo-optic properties which enable high-power operation, it also narrows the Yb:YAG gain spectrum as compared to room temperature, limiting the minimum pulsewidth to a few picoseconds. In comparison, Yb:LiYF4 (YLF) enjoys similar thermo-optic benefits from cooling, yet maintains a significantly broader bandwidth. This material offers the possibility of femtosecond pulses from a kilowatt-class laser. We present the results of a chirped-pulse amplification system based on cryogenic Yb:YLF. The amplifier produces 10-mJ pulses at 100-W average power with excellent beam quality. At 4.5 mJ, the pulses have a spectral width of 2.2 nm and compress to 700 fs in duration. We discuss the possibility of modifying this system for a pulse duration of a few-hundred femtoseconds, as well as scaling to higher powers.

8381-29, Session 7

Cryogenic Yb:YAG picosecond laser with high average power visible and ultraviolet harmonic generation

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Cryogenic Yb:YAG lasers operating at 1029 nm have been demonstrated at Snake Creek Lasers with high average power CW and ultrafast output powers, and provide near diffraction-limited output beams that are ideal for applications in harmonic generation. We describe experiments that have produced high average power green output power at 515 nm as well as preliminary experiments producing UV output power at 257 nm. Frequency doubling experiments have used a 20 mm long non-critically phase-matched LBO crystal mounted in a constant temperature oven. A mode-locked Yb fiber laser operating at 50 MHz was used to drive a two Yb:YAG cryogenic amplifier system, producing hundreds of watts of average power output with a FWHM pulsewidth of 12 ps. Doubling efficiencies of > 50 % have been observed. For frequency quadrupling, we have used a hydrothermally grown KTTP crystals grown at Clemson University and Advanced Photonic Crystals. KBBF offers unprecedented UV transmission down to 155 nm, and was used in a Type I phase-matching configuration. The properties of KBBF will be discussed, as well as the experimental results observed and conversion efficiency.

8381-30, Session 7

High-efficiency resonantly pumped Ho3+:YVO4 2.05-µm laser

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We report on what we believe to be a record efficiency Ho3+:YVO4 laser. The cryogenically cooled gain medium, Ho3+:YVO4, was resonantly pumped at ~1.93 µm using a tunable Tm fiber laser to produce laser output at 2.054 µm. Characterization, loss analysis and spectroscopy of the Ho3+: YVO4 laser will be presented.

8381-31, Session 7

Spectroscopic properties and laser performance of resonantly pumped Er:GdVO4

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Er-doped laser materials have been established as one of the best choices in designing resonantly-pumped, highly scalable eye-safe lasers operating in 1.6 micrometer range. A variety of lasers such as Er:YAG, Er:Sc2O3 and Er:NaY(WO4)2 have demonstrated an efficient low quantum defect (QD) operation, especially at cryogenic temperatures due to improved spectroscopic, thermo-mechanical and thermo-optical properties. While the absorption and laser cross-sections become stronger, they also become much narrower and can significantly hinder pumping efficiency even with narrow-linewidth pump sources.

"Disordered" laser hosts, such as Er:NaY(WO4)2 exhibit very broad absorption lines, but their thermal conductivity is low, approaching that of glasses. Uniaxial Er:YVO4 offers some compromise - it has rather high absorption cross-sections and broader absorption lines suitable for resonant pumping which helped to demonstrate an efficient laser operation and to simplify the laser design.

As a laser host material, RE-doped gadolinium vanadate (GdVO4) is a close analog to YVO4 which has been already successfully commercialized and widely used. Its main advantage over YVO4 is in nearly twice as high thermal conductivity - 11 W/m·K at room temperature. While, an excellent low QD performance of resonantly-pumped Er:YVO4 laser has been recently demonstrated, the laser potential of the Er:GdVO4 crystals was not been yet adequately explored.

Here we present spectroscopic characteristics of Er3+:GdVO4 and its laser performance under resonant pumping at cryogenic and room temperatures. This is believed to be the first reported resonantly-pumped laser based on 4I13/2 - 4I15/2 Er3+ transitions in Er3+:GdVO4 single crystal.

8381-32, Session 8

Recent results for the Raytheon RELI program

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We describe our approach and latest results for Raytheon's RELI (Robust Electric Laser Initiative) program. Our architecture leverages a slab-based, Master Oscillator / Power Amplifier (MOPA) architecture based on Raytheon's unique planar waveguide amplifier. Technical objectives for this effort are to demonstrate > 25 kW output with excellent beam quality and an electrical to optical efficiency > 30%. The planar waveguide architecture provides compact packaging and is inherently scalable to 100 kW or greater in a single beam line. We report on the latest progress and test results for the program.

8381-33, Session 8

Active coherent beam combining of fiber lasers by multiplexed volume Bragg gratings

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In order to overcome the power limitations of fiber lasers, beam combining techniques such as spectral beam combination (SBC) and coherent beam combination (CBC) are being actively researched. Specifically, CBC can be divided into techniques that use active or passive techniques to force coherence between array elements. While passive scalability appears limited [1], active CBC with channel scalability of 64 elements has been reported [2] and channel counts of up to 100-200 appear feasible. Towards that end, we report active beam combining of fiber lasers via multiplexed volume Bragg gratings (VBGs) recorded in photo-thermo-refractive (PTR) glass. Previously, both high density SBC and passive coherent coupling of fiber lasers have been demonstrated with high-efficiency VBGs [3].

Accordingly, we demonstrate a compact CBC system based on multiplexed VBGs with LOCSET active phase locking [4]. Five VBGs were multiplexed in a single PTR wafer such that a common (degenerate) for all gratings Bragg angle at the specified wavelength of 1064 nm was enabled. Consequently, the multiplexed VBG provides efficient superposition in both the near and far fields of five coherent beams. Initial 5-element beam combination experiments were run at moderate output power levels (80W) demonstrating good efficiency (>85%) and near diffraction limited beam quality (M2=1.1). Experiments detailing scaling to higher combined powers (~400 W) are discussed. This is the first demonstration of active CBC via VBGs. Specifically; the use of multiplexed volume gratings in a single substrate enables possible upscaling of laser array brightness through simultaneous spectral and coherent beam combining.

8381-34, Session 8

Laser transceivers for future NASA missions

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The Earth science laser missions currently being developed by NASA were recommended by the National Research Council (NRC) Earth Science Decadal Report published in 2007. The Ice Cloud and Land Elevation Satellite-2 (ICESat-2) Advanced Topographic Laser Altimeter System (ATLAS) is a tier-1 mission and is scheduled for launch in 2016. The Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS) mission is a tier-2 mission in the NRC report and will be the first laser spectroscopy from space with the objective to profile aerosol and cloud for climate and water cycle; ocean color for open ocean biogeochemistry. The Lidar Surface Topography (LIST) is a recommended tier-3 program in the NRC report. The objective of the mission is to globally map the topography of the Earth's solid surface with 5 m spatial resolution and 10 cm vertical precision, as well as the height of overlying covers of vegetation, water, snow, and ice. The Gravity Recovery And Climate Experiment (GRACE) Follow-On (GRACE-FO) and GRACE-2 missions are also recommended missions in the decadal survey that measure the gravitational field of Earth. Here we will describe the transceiver requirements.

The ATLAS instrument requires a 10 kHz repetition rate, 2 mJ pulse energy and 1.5 ns pulse width laser transmitter . We have developed solid-state, fiber and planar waveguide candidate laser transmitters. We examined and tested Geiger-mode, conventional and hybrid photomultiplier detector candidates.

Our approach for the ASCENDS instrument uses two tunable pulsed laser transmitters allowing simultaneous measurement of the absorption from a CO2 absorption line in the 1570 nm band, O2 absorption in the oxygen A-band, and surface height and atmospheric backscatter in the same path. A tunable laser is stepped in wavelength across a single CO2 line for the CO2 column measurement, while simultaneously a laser is stepped across a line doublet near 765 nm in the Oxygen A-band for an atmospheric pressure measurement. Both lasers are pulsed at a ~8kHz rate, and the two absorption line regions are sampled at each wavelength step at typically ~1 KHz. We are examining fiber and planar waveguide laser architectures. Near-infrared single photon sensitive avalanche photodiodes and photomultiplier tubes are detector candidates.

The baseline laser for GRACE-FO is the Non-Planar Ring-Oscillator (NPRO) Nd:YAG laser. A similar laser system was flown on the NFIREto TerraSAR-X laser communication experiment . We have been investigating alternative laser technology for the GRACE-FO, GRACE-2 and the Laser Interferometer Space Antenna (LISA) missions. A strong contender is a very narrow linewidth external cavity laser diode.

8381-35, Session 8

Integrated 100 W thulium fiber MOPA system

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Development of thulium fiber laser systems with high average power has rapidly accelerated within the past 10 years, however the immaturity of a variety of fiber-based components in particular pump combiners and optical isolators for use in the 2 m wavelength regime continues to limit the development of fully integrated high power polarized thulium fiber laser systems. We report on the performance of an integrated Tm:fiber master oscillator power amplifier (MOPA) system, producing 100 W CW output with quasi diffraction-limited beam quality, sub-200 pm spectral linewidth (FWHM), and >10 dB polarization extinction ratio at 2034 nm.

The system consists of an oscillator based upon single-mode polarization maintaining (PM) thulium-doped fiber with 10/130 m core/cladding diameters pumped with a 35 W, 793 nm diode. The amplifier is based on a large mode area PM fiber with 25/400 m core/cladding diameters, pumped with six 70 W, 793 nm diodes through a 6+1:1 high power pump combiner. The oscillator is spliced to the amplifier via a fiber coupled optical isolator and a mode field adaptor. This nearly completely integrated laser system produces high power, with >10 dB polarization extinction ratio and diffraction-limited beam quality. To the best of our knowledge this is the highest power produced from an integrated polarized Tm:fiber laser.

8381-59, Poster Session

Beam combining with using beam shaping

A. V. Laskin, AdlOptica Optical Systems GmbH (Germany); L. B. Glebov, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); V. Laskin, AdlOptica Optical Systems GmbH (Germany)

Performance of spectral beam combining depends on thermal effects on the optical components like volume Bragg gratings used for spectral selectivity of the beams combined. These thermal effects are results of absorption of laser radiation and in case of high power lasers can lead to reduction of efficiency of combining and losses. For example the Gaussian intensity distribution of laser beam leads to higher temperature in the central part of a grating and, hence, changing its operating specifications. Homogenizing of the temperature profile over the working field of a volume Bragg grating would increase efficiency of its operation. This can be realized through applying the beam shaping optics, for example refractive field mapping beam shapers providing high flexibility in building various optical setups due to their unique features: almost lossless intensity profile transformation, providing flattop, super Gauss or inverse Gauss profiles with the same beam shaper, saving of the beam consistency, high transmittance and flatness of output beam profile, extended depth of field, capability to adapt to real intensity profiles of TEM00 and multimode laser sources.

This paper will describe some design basics of refractive beam shapers of the field mapping type, with emphasis on the features important for building and applications of high-power laser sources. There will be presented results of applying the refractive beam shapers in real research installations.

8381-60, Poster Session

High-energy laser tactical decision aid (HELTDA) for mission planning and predictive avoidance

J. Burley, S. T. Fiorino, R. M. Randall, R. J. Bartell, S. J. Cusumano, Air Force Institute of Technology (United States)

This study demonstrates the development of a high energy laser tactical decision aid (HELTDA) by the AFIT/CDE for mission planning HEL weapon system engagements as well as centralized, decentralized, or hybrid predictive avoidance (CPA/DPA/HPA) assessments. Analyses of example HEL mission engagements are described as well as how mission planners are expected to employ the software. Example HEL engagement simulations are based on geographic location and recent/current atmospheric weather conditions. The atmospheric effects are defined through the AFIT/CDE Laser Environmental Effects Definition and Reference (LEEDR) model or the High Energy Laser End-to-End Operational Simulation (HELEEOS) model upon which the HELTDA is based. These models enable the creation of vertical profiles of temperature, pressure, water vapor content, optical turbulence, and atmospheric particulates and hydrometeors as they relate to line-by-line layer extinction coefficient magnitude at wavelengths from the UV to the RF. Seasonal and boundary layer variations (summer/winter) and time of day variations for a range of relative humidity percentile conditions are considered to determine optimum efficiency in a specific environment. Each atmospheric particulate/hydrometeor is evaluated based on its wavelength-dependent forward and off-axis scattering characteristics and absorption effects on the propagating environment to and beyond the target. In addition to realistic vertical profiles of molecular and aerosol absorption and scattering, correlated optical turbulence profiles in probabilistic (percentile) format are used. Physics-based cloud and rain rate scenarios are additionally considered to complete the realistic engagement environments necessary for comprehensive understanding of HEL weapon system performance.

8381-61, Poster Session

Laser photography system: hardware configuration

M. Piszczek, K. Rutyna, M. Kowalski, M. Zyczkowski, Military Univ. of Technology (Poland)

Using multisensor and multispectral monitoring systems is one of the most important aspects of preventing open space and public places threats. Modern vision systems can offer big possibilities in a field of visualization and measurement. Such solutions play essential role in present security and defense systems. One of very interesting group of imaging devices are the Range Gated Imaging (RGI) cameras. Laser Photography System (LPS) proposed by authors is a RGI camera system that offers big observation-measurement capabilities. The LPS offers a capability of precise visualization of chosen fragment of space for detection, recognition and identification of terrorist threats. The Range Gated Imaging (RGI) technology implemented in the Laser Photography Device is one of the most modern solutions amongst imaging technologies. This technique connects distributing abilities of the traditional vision systems, and lower illumination and weather conditions sensitiveness as in radars. One of the LPS features is a possibility to acquire image of strictly defined distance and space depth. Extracted images are not just only a projection of space for some angular observation range but they are representation of strictly defined 3D space fragment. Spatial resolution depends on timing parameters of illuminator and detection module. Imaging range is connected with electromagnetic wave propagation conditions. There is possibility of imaging in distances far than 1km with spatial resolution below 1m in standard atmospheric conditions using high energetic nanosecond laser impulses. The aim of this article is to discuss the properties and hardware configuration of the Laser Photography System.

8381-64, Poster Session

Laser-induced microwave emission from dual laser illumination of solid targets

J. A. Miragliotta, S. Varma, B. Brawley, J. W. Maclachlan Spicer, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Recent investigations in our lab and elsewhere have shown that electromagnetic pulses (EMP) in the microwave and RF regions of the spectrum are generated during femtosecond laser-matter interactions when the laser source is above the threshold to ablate and ionize an illuminated target. In an earlier laser-induced EMP investigation, our group examined the X-band microwave emission profiles from a variety of ablated materials--metals, semiconductors, and dielectrics-and determined the laser fluence dependence of the radiation in the 10 GHz range for single pulse illumination (energy/pulse ~ 50 mJ, pulse width ~ 30 fs, laser diameter at target ~200 microns). We have extended these initial measurements to include a dual laser illumination configuration where two laser pulses, a femtosecond source (> 1 Terawatt) and a nanosecond laser, were used to generate and control the amplitude of microwave emission from an ablated target. Laser induced EMP in the 1 to 10 GHz region was found to be dependent on the fluence ratio of the two laser sources as well as the relative timing delay between the pulses. Additionally, the temperature and electron density of the plasma were monitored by time-resolved spectroscopy of neutral atom and ion line emissions from the ablated target and correlated to the production of microwave emission.

8381-65, Poster Session

A study of Huygens-Fresnel diffraction inside a laser cavity

N. S. Prasad, D. Park, NASA Langley Research Ctr. (United States)

This paper will present recent progress achieved in computer models depicting the evolution of diffractive processes through passive and active cavities as the number of passes (or the length of propagation) increases. The overall objective is to visualize how the spatially stable eigen-modes evolve with propagation. Using the Huygens-Fresnel diffraction equation inside a laser cavity, the spatial and temporal characteristics of the output beam are being investigated. To start with, Bessel mode propagation is studied inside a free space Fabry-Perot cavity followed by a resonator consisting of a laser gain medium. Next, simulation using Finite Difference Time Domain (FTTD) is carried out to understand mode evolution in the near-field regime. Using MATLAB based codes, 2D and 3D mode evolution profiles obtained will be discussed. This research is important for understanding the nature of photons related to generation, evolution, and propagation inside a laser cavity. A better understanding of the behavior of light inside a laser cavity is anticipated to provide insights into tailoring of modes, enhancements in efficiency, and improvements in coherence.

8381-66, Poster Session

Novel silicon/aluminum alloys for use as cold plate materials in cryogenically cooled solid state lasers

J. F. Schill, U.S. Army Research Lab. (United States); A. J. Ogilvy, Sandvik Osprey Ltd. (United Kingdom)

The issue of heat transfer in high energy lasers has been a serious problem for years. One of the ways that has been shown to be a valid method of mitigating this problem is the use of low quantum defect solid state materials operated at cryogenic temperatures. A significant problem exists due to mismatch of coefficient of thermal expansion (CTE) and repeatedly cycling through a temperature range of ~200 K. Other groups, T.Y. Fan et al at MIT Lincoln Laboratory, have used ingenious crystal holders to overcome this problem. In this paper, we suggest the use of Silicon/Aluminum (Si/Al) alloys produced by Sandvik Osprey Ltd. that can have their CTE altered easily to match the CTE of whatever crystal material is chosen and still have a thermal transfer coefficient suitable for large heat transfer. We show the results of testing three different Si/Al alloys for CTE and thermal conductivity. We further test the material in a flow boil off cryogenic cooling system that shows the CE6 alloy material is capable of heat transfer of 200 W/cm2 , with cold plate temperatures maintained below 110 K. The CE6 material has a CTE that almost exactly matches YAG from 90-300K. We also present results of damage testing as we cycle a YAG crystal soldered to CE6 with indium solder through numerous cycles from 90-300 K.

8381-67, Poster Session

Recent developments in coherent laser combination using a self-Fourier cavity

C. Corcoran, Corcoran Engineering Inc. (United States); F. M. Durville, Optical Fiber Systems, Inc. (United States)

We will present our latest results on coherent laser combination using a Self Fourier (SF) cavity. Experimental results will be presented on the successful operation of a 21 element multicore fiber laser as a coherent array. We will also present experimental results on the operation of a 30 micron core fiber laser in a single transverse mode by providing feedback to the fiber from a single-element Self-Fourier cavity.

8381-68, Poster Session

Large-area, high-power VCSEL pump arrays optimized for high-energy lasers

C. Wang, J. C. Geske, H. Garrett, T. Cardellino, D. S. Renner, FLIR Electro-Optical Components (United States)

Practical, large-area, high-power diode pumps for one micron (Nd, Yb) as well as eye-safer wavelengths (Er, Tm, Ho) are critical to the success of any high energy diode pumped solid state laser. Diode efficiency, brightness, availability and cost will determine how realizable a fielded high energy diode pumped solid state laser will be. 2-D Vertical-Cavity Surface-Emitting Laser (VCSEL) arrays are uniquely positioned to meet these requirements because of their unique properties, such as low divergence circular output beams, reduced wavelength drift with temperature, scalability to large 2-D arrays through low-cost and high-volume semiconductor photolithographic processes, high reliability, no Catastrophic Optical Damage (COD) failure, and radiation and vacuum operation tolerance. Data will be presented on the status of FLIR-EOC's VCSEL pump arrays. Analysis of the key aspects of electrical, thermal and mechanical design that are critical to the design of a VCSEL pump array to achieve high power efficient array performance will be presented.

8381-36, Session 9

Polycrystalline transparent YAG ceramics for mid-infrared, solid-state lasers

D. Y. Tang, J. Zhang, Nanyang Technological Univ. (Singapore); D. Shen, Xuzhou Normal Univ. (China); J. Ma, Nanyang Technological Univ. (Singapore)

Compared to single crystals, ceramics YAG can be produced with large size and high doping concentration with uniform doping distribution. After A. Ikesue reported the first laser oscillation in Nd:YAG ceramics, various laser ceramics doped with different rare earth ions had been fabricated during the past 15 years. However it is still a challenge work to make the transparent ceramic YAG with optical quality close to single crystals. In this talk we will present our recent progress on fabricating high optical

quality transparent YAG ceramics. The effects of stoichiometry, sintering aids, and sintering conditions on microstructure and further the optical quality of the sintered ceramics were extensively investigated. At the optimized fabrication conditions, various rare earth doped YAG ceramics such as Er3+:YAG, Ho3+:YAG and Tm3+:YAG with different doping concentrations are fabricated successfully. Their applications as the gain media for mid-infrared solid state laser applications are demonstrated. In particular, a highly efficient polycrystalline Tm:YAG ceramic laser in-band pumped by a Er:YAG ceramic laser at 1617 nm were achieved. By using a 4 at.% Tm:YAG ceramic, a maximum output power of 7.3 W at 2015 nm was obtained under 12.8 W of incident pump power, corresponding to a slope-efficiency with respect to incident pump power of 62.3%. The result shows great potential for the future applications of the polycrystalline laser ceramics.

8381-37, Session 9

Influence of processing variables on the optical attenuation of polycrystalline yttrium aluminum garnet (YAG) fibers

H. J. Kim, UES, Inc. (United States) and Air Force Research Lab. (United States); N. G. Usechak, Air Force Research Lab. (United States); H. D. Lee, UES, Inc. (United States) and Air Force Research Lab. (United States); G. E. Fair, Air Force Research Lab. (United States)

YAG is a clear choice for the gain media for high power laser applications, and the advantages of ceramic YAG relative to the single crystal form have recently been demonstrated successfully in terms of production cost, mechanical/optical properties, and high dopant concentrations. In addition, a novel doped polycrystalline optical fiber is a promising alternative to bulk media due to advantages such as enhanced cooling efficiencies, vibration resistance, long interaction lengths, and the inherent elimination of free space optics when integrated into lasers and systems. This work focuses on the development and characterization of optical-quality polycrystalline YAG fibers. By utilizing robust ceramic processes, we are able to produce < 30-µm diameter, optically transparent, polycrystalline YAG fibers. In this presentation, we report the loss of these fibers and the effects of processing variables on their attenuation in detail along with a discussion of the experimental technique used to make these measurements. In addition, comparisons will be made between the behavior of doped/undoped and clad/unclad polycrystalline YAG fibers.

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8381-38, Session 9

Initial testing of a ceramic Yb:YAG edge-pumped, solid state disk laser

J. Vetrovec, D. A. Copeland, A. S. Litt, Aqwest, LLC (United States); D. Du, General Atomics Aeronautical Systems, Inc. (United States)

We report on initial testing of a kilowatt-class edge-pumped solid-state disk laser amplifier being developed for chirped pulse amplification in ultra-short pulse lasers. The laser uses a novel Yb-doped composite YAG ceramic laser disk with integral features for suppression of amplified spontaneous emission (ASE). Edge-pumped geometry enables low Yb doping, which translates to far lower laser threshold and much reduced heat load than experienced by conventional face-pumped thin disk lasers. The latter translates to ultra-low thermo-optical / thermomechanical distortions, thus enabling excellent beam quality. The laser disk is cooled by a microchannel heat sink offering 1) ultra-low thermal resistance, 2) uniform extraction of waste heat from the disk, and 3) unparalleled dimensional stability for ultra-low optical distortions. Other advantages of the edge-pumped laser architecture include compact construction and easy scalability to higher power levels. This work was in part supported by the US Army ARDEC Contract Number W15QKN09C0156.

8381-39, Session 9

Towards high-quality optical ceramics for high-energy laser (HEL) applications

H. D. Lee, K. Keller, B. Sirn, M. Barkneh, UES, Inc. (United States)

It is well established that optical ceramics, including YAG, Lu2O3, and Y2O3, can serve as host materials for high power lasers. The advantages of ceramic-based laser gain media compared to single crystal-based gain media are also widely recognized. Nevertheless, the actual deployment of these materials still hinge on the quality of the ceramic gain media. Highly sinterable powders with a high chemical purity (>99.99%) are essential, along with robust processing technologies. UES has been developing powder production processes in order to meet the needed powder quality (YAG, Lu2O3, and Y2O3). These powders can be further processed into dense, optically transparent products in various forms (discs, slabs, rods, tubes, and fibers).

In this presentation, we report on UES's powder production technology and advanced ceramic processing technologies that are used to produce various forms of polycrystalline laser gain media. In addition, we present preliminary results of doped ceramic fibers for use in high energy laser applications.

8381-40, Session 9

A 243 mJ, eye-safe, frequency-agile, optical parametric oscillator-based DIAL transmitter

M. D. Wojcik, R. Foltynowicz, Space Dynamics Lab. (United States)

We demonstrate a high- energy (215 mJ), eye-safe, 1.533 m KTA ring-cavity optical parametric oscillator (OPO) for use as an elastic lidar source. The OPO was pumped by a single longitudinal mode (SLM), 7 ns FWHM, 30 Hz, Q-switched, Nd:YAG at 1064 nm. Our interest was to convert this source into a potential DIAL transmitter that not only was eye-safe and high-energy, but also had a narrow linewidth and used a non-mechanical means to rapidly switch frequencies. By making some minor design modifications to our OPO and injection seeding the OPO with a DFB diode laser, we demonstrate and characterize a NIR-DIAL source that produces 243 mJ/pulse with a spectral linewidth FWHM of 157 MHz and has a possible frequency switching rate in the upper hundreds of MHz.

8381-41, Session 9

Athermal slab laser system

M. E. Kushina, Northrop Grumman Cutting Edge Optronics (United States); G. Kemner, W. F. Collins, Northrop Grumman Aerospace Systems (United States)

Northrop Grumman Aerospace Systems-Cutting Edge Optronics (NGAS-CEO) has developed a Diode Pumped Solid State Laser (DPSSL) for high power LIDAR & LADAR applications (average laser powers > 30 W). NGAS-CEO has combined its high temperature, athermal laser diode technology with a proprietary slab design to build a laser system that operates over wide ambient temperatures without requiring active Thermo-Electric or compressor based, liquid cooling. This significantly reduces overall system Size, Weight and Power (SWaP) requirements making this laser technology well suited for small aircraft and UAV platforms. The NGAS-CEO laser technology can be used in multiple system architectures from oscillator only designs to Master Oscillator Power Amplifier (MOPA) configurations. The gain module itself can even be used in single or multi-pass amplifier configuration. This laser technology is extremely flexible and robust and is easily scalable to higher laser output powers.

8381-42, Session 10

Ultra-short-pulsed, fiber-ring laser using photonic crystal fiber

S. Ma, W. Li, H. Hu, N. K. Dutta, Univ. of Connecticut (United States)

A new scheme to generate high speed optical pulse train with ultra short pulse width is proposed and experimentally studied. Two-step compression is used in the scheme: 20 GHz and 40 GHz pulse trains generated from a rational harmonic actively mode-locked fiber ring laser is compressed to FWHM ~1.5 ps using adiabatic soliton compression with dispersion shifted fibers (DSF). The pulse trains then undergo a pedestal removal process by transmission through a cascaded two photonic crystal fiber (PCF)-nonlinear optical loop mirrors (NOLM) realized using a double-ring structure. The shortest output pulse widths measured was ~650 fs for 20 GHz pulse train and ~570 fs for 40 GHz pulse train respectively. The RF spectrum shows signal to noise ratio of greater than 30 dB. Theoretical simulation of the NOLM transmission is conducted using the split-step Fourier method. The result shows that two cascaded NOLMs can improve the compression result compared to single NOLM transmission.

8381-43, Session 10

911nm fiber laser-based source for underwater application at blue wavelengths

D. Engin, J. Fouron, A. Huffman, Y. Chen, F. Fitzpatrick, R. L. Burnham, S. Gupta, Fibertek, Inc. (United States)

Although the first demonstration of fiber laser used an Nd-doped fiber operating at 1.06um, it is not used due to superior and power-scalable Yb-fiber laser performance at 1-um wavelengths. However, Nd3+-ions allow laser operation in the 900-950nm shorter wavelength region. This 4F3/2 4I9/2 laser transition is difficult to achieve in conventional Nd-doped bulk solid-state laser host, due to low gain, competing high gain at longer wavelengths, and the need for high pump intensity. An Nd-doped fiber waveguide gain medium mitigates such issues. Frequency-doubling to 450-475nm accesses the lowest extinction band for deep ocean waters, suited for Navy underwater optical communication. In particular, 911nm laser source is highly desired as the Cs-455nm atomic line filter can virtually eliminate the background, permitting long range photon-limited operation under any ambient.

We demonstrate a laser diode seeded, all-fiber multi-stage Nd-fiber master-oscillator power-amplifier (MOPA) operating at 911nm. The first two stages use core-pumped single-mode Nd-doped fiber. In cw operation, 10dB gain with 60mW output power is achieved from the first stage. With two stages 35% optical-optical efficiency is expected, with >0.3W output power, limited only by available single-mode 808nm pump laser diodes. This is used to seed an Nd-doped clad-pumped large-mode-area fiber amplifier with large core/clad ratio, to produce few Watts of cw power. Driving the 911nm seed laser diode in pulsed mode, and managing the amplified spontaneous emission at long wavelengths, near kW peak powers are achievable, suited for efficient second-harmonic-generation. Detailed fiber-amplifier simulations are also discussed, identifying design and performance tradeoffs for various fiber waveguide designs. We also discuss use of such fiber-MOPA seeder in a solid-state optical-parametric-amplifier architecture, for scaling to multi-mJ output at kHz rates.

8381-44, Session 10

Waveform agile, high-power, fiber laser illuminators for directed-energy weapon systems

D. Engin, F. Kimpel, S. Gupta, Fibertek, Inc. (United States)

Directed-Energy Weapon (DEW) systems need acquisition, coarse- and fine-tracking of potential threats prior to an engagement decision. For active fine-tracking, a high power cw laser illuminator is commonly used, but a high repetition rate pulsed source can also provide range information, for predicting its trajectory. In addition to providing wavelength separation from the 1064nm primary DEW beam, shorter wavelength (260W average power for 100nsec pulses at high repetition rate has been demonstrated with 78% optical efficiency. Using large core-to-clad ratio fibers to overcome re-absorption loss in clad-pumped stage, managing ASE in multi-stage Yb-fiber-MOPA, controlling gain and parasitic lasing due to residual reflections, and algorithm based control and pre-compensation of the optical pulse-shape, power scaling to >500W average power is possible. Similar considerations apply to a 1.5um fiber-MOPA laser illuminator, as the gain and saturation parameters are similar. However, the 1.5um transition has poor conversion efficiency (<30%) and thermal issues become significant. We also present comprehensive fiber-MOPA simulation that accurately models the output for various pulsed waveforms.

8381-45, Session 10

Very large mode area Er-doped high aspect ratio core (HARC) rectangular fiber producing 5-mJ, 13-nsec pulses at 1572 nm

V. Khitrov, V. V. Shkunov, D. A. Rockwell, Y. A. Zakharenkov, F. P. Strohkendl, Raytheon Space & Airborne Systems (United States)

We are developing a family of custom high-aspect-ratio-core (HARC) and semi-guiding high-aspect-ratio core (SHARC) fibers to scale CW and pulsed power. The high-aspect ratio rectangular core enables scaling to a very large area while retaining a thin, mechanically flexible narrow dimension that allows the fiber to be coiled. Mode control is achieved in the narrow dimension by bend-induced losses, as in LMA fibers, and in the wide dimension by gain filtering and, in SHARC versions, diffractive loss filtering. The Er:HARC fibers were fabricated by OFS Laboratories; the uniformly Er-doped core has 20 dB/m absorption at 1530 nm. The specific fiber used in the amplifier experiments has core dimensions of 30 x 580 µm^2, yielding a total area of 17,400 µm^2.

The HARC fiber amplifier was core-pumped by a CW 5-W 1470-nm diode. The pulsed seed signal into the amplifier was generated by a Nd:YAG-pumped OPO tuned to 1572 nm. Time averages of the 1572 nm amplified pulses reached 4.5 mJ, but many individual pulses exceeded 5 mJ. To our knowledge, these results represent the highest reported Er-doped single-fiber pulse energies in the nsec regime. CW slope efficiencies at 1560 nm reached 40 %.

Our amplifier model achieves good agreement with the data, and it predicts that an optimized HARC fiber having a 15 x 250 µm^2 core can produce energies > 10 mJ with pulse lengths ~ 10 nsec. Extending the core width to ~ 1.5 mm would enable single-fiber energies > 30 mJ in the same pulse-length regime.

8381-46, Session 10

Supercontinuum: broad as a lamp, bright as a laser, now in the mid-infrared

P. M. Moselund, C. Petersen, NKT Photonics A/S (Denmark); S. Dupont, Aarhus Univ. (Denmark); O. Bang, Technical Univ. of Denmark (Denmark); S. R. Keiding, Aarhus Univ. (Denmark)

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Based on the experience gained developing our market leading visible spectrum supercontinuum sources NKT Photonics has built the first mid-infrared supercontinuum source based on modelocked picosecond lasers. The source is pumped by a ≈2 um laser based on a combination of erbium and thulium lasers and ZBLAN fibers and currently generates a 1.45-3.7 µm spectrum. The research in ongoing and significantly wider spectra should be realized by the time of the conference.

The picosecond pumping gives better control over the generated spectrum than the more commonly used nanosecond pumping and the high pulse repetition rates can reduce noise. In this talk we describe our results with mid infrared supercontinuum generation in soft-glass fibers and what potentials we see in this new type of mid-infrared light source which can transform mid-infrared spectroscopy, microscopy and countermeasures as its visual counterpart has already transformed visual imaging.

We will also present the results we have obtained by applying the source for mid-infrared microscopy where absorption spectra can be used to identify he chemical nature of different parts of a sample.

8381-47, Session 11

Experimental and theoretical studies of phase modulation in Yb-doped fiber amplifiers

A. Flores, C. A. Lu, C. Robin, I. Dajani, Air Force Research Lab. (United States)

We present detailed studies of the effect of phase modulation on stimulated Brillouin scattering (SBS) in ytterbium-doped fiber amplifiers. We consider three phase modulation formats: sinusoidal, pseudo-random bit sequence (PRBS), and white noise source (WNS). For the sinusoidal case, SBS suppression is compared in relation to modulation depth ranging from 0 to π and modulation frequency ranging from 30 MHz to 500 MHz. The SBS thresholds for PRBS and WNS are determined and compared up to 20 GHz of modulation frequency. Furthermore, we compare our results to the theoretical predictions of a time-dependent SBS model.

8381-48, Session 11

All-glass resonantly cladding-pumped Yb-free Er-doped fiber laser

J. Zhang, J. McElhenny, V. Fromzel, M. Dubinskii, U.S. Army Research Lab. (United States)

We have recently demonstrated significant scaling potential of resonantly cladding-pumped Yb-free, Er-doped fiber lasers. With the resonant pumping approach heat deposition can potentially be limited by low quantum defect only, which opens up significant space for fiber laser power scaling with very minor, if any, thermal management complications. Reported here are the most recent results of power scaling of fully integrated, all-glass, resonantly cladding-pumped Yb-free Er-doped fiber lasers and amplifiers.

8381-49, Session 11

High peak power two micron single frequency Q-switched fiber laser

S. Jiang, AdValue Photonics, Inc. (United States)

High-power single-frequency pulsed lasers operating in the spectral region near 2 micron are highly desirable for many applications including airborne and space-borne coherent lidar for atmospheric sensing, nonlinear frequency conversion for the generation of narrow-band mid-infrared radiation as well as a pump source for mid-infrared supercontinuum generation.

We demonstrated 2 micron continuous wave single frequency narrow linewidth fiber laser and Q-switched single frequency fiber laser. A single-mode Tm-doped fiber amplifier was used to boost the output power of Q-switched single-frequency laser pulses. kW-level single-frequency laser pulses from an all-fiber Tm-doped source was generated. Short length of the active fiber was used in the fiber amplifier, which allows for suppressing nonlinear effects in the active fiber. Laser spectral linewidth was monitored with the fiber based scanning Fabry-Perot interferometer. Our on-going development of mJ level high energy pulse 2 micron single frequency Q-switched fiber laser will be described in the presentation as well.

8381-50, Session 11

Kilowatt monolithic PCF fiber amplifers for narrow linewidth and single mode operation

D. L. Sipes, Jr., J. D. Tafoya, D. S. Schulz, Optical Engines, Inc. (United States); C. G. Carlson, B. G. Ward, U.S. Air Force Academy (United States)

Photonic Crystal Fibers (PCF) are the most suitable fibers for multi-kW fiber lasers and amplifiers because the low NA of the active core due to the precise index control of the photonic crystal fiber which allows for larger single mode core diameters. The Very high NA of the air clad outer pump cladding makes possible the use of large pump clad diameters allowing for a higher degree of pump integration. To date it has been difficult to use PCF fiber for high power applications due to the lack of suitable fiber interface devices such as pump power combiners. A kW class single mode, PM, narrow linewidth fiber lasers has been constructed in an all fiber, monolithic architecture. The pumps are based on a highly affordable multi fiber coupled laser diode stack design and the combiner is based on Etched Air Taper combiner technology. Construction and performance issues related to this design will be reported as well.

8381-51, Session 11

CW and pulsed performance of Tm-doped photonic crystal fiber lasers

P. Kadwani, R. A. Sims, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); L. Leick, J. Broeng, NKT Photonics A/S (Denmark); L. Shah, M. C. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We investigate the performance of a thulium-doped photonic crystal fiber (PCF) with 50 m core diameter and an ultra-large mode area >1000 m2. Passive and CW characterization confirm that the output of this PCF is single-mode and highly polarized for bend diameters as small as 35 cm. To our knowledge, this is the largest mode area of any single-mode, flexible PCF.

In order to examine the potential of this fiber for high peak power generation, we have constructed an actively Q-switched oscillator producing 8.9 kW peak power with 435 J, 49 ns pulses. The quasi diffraction-limited beam quality and >15 dB polarization extinction ratio in combination with high peak power make this very simple laser system attractive as a pump for mid-infrared light generation via optical parametric and broadband continuum processes.

We are currently investigating various master-oscillator power-amplifier configurations to enable the generation of higher peak powers, by increasing output pulse energy and decreasing pulse duration. These recent results confirm the potential of both thulium and PCF to achieve high peak powers, possibly surpassing ytterbium-doped fiber lasers.

8381-52, Session 12

60 Watt, CW Guidestar Laser with Pound-Drever-Hall Locking

J. Stohs, Air Force Research Lab. (United States)

We report the completion and initial testing of a high power, single frequency, CW guidestar laser for adaptive optics applications. The system is based on the sum frequency generation of a 589 nm yellow beam derived from laser beams at 1064 and 1319 nm overlapping in a lithium triborate crystal. The input beams are generated in frequency stabilized ring laser cavities using diode pumped Nd:YAG rods which have individual temperature and diode current controls to mitigate thermal lensing. Frequency stabilization is achieved with piezo-driven mirrors in the ring lasers and the Pound-Drever-Hall signal analysis technique to lock them to their respective reference laser sources. The ring laser for 1064 nm is capable of greater than 60 W of power, and the ring laser for 1319 nm is capable of 35-38 W. With these available power levels, a yellow beam at 589 nm was generated with an output power of 60 W, although the beam and power were more stable at 55 W. To the best of our knowledge this is the highest power, single frequency, CW, 589 nm beam achieved to date.

8381-56, Session 12

Demonstration of a yellow dysprosium laser

S. P. O'Connor, S. R. Bowman, U.S. Naval Research Lab. (United States)

Direct diode pumping revolutionized the solid state laser industry in efficiency and cost for lasers in the near infrared and the mid infrared spectrum. Newly-available GaN based laser diodes provide a pathway to extending diode pumped solid-state lasers into the visible. Here we report the demonstration of the first diode-pumped visible dysprosium laser. This system uses Dy3+ doped Y3Al5O12 as the gain medium and operates as a four-level laser on the 4F9/2 6H13/2 transition at 583nm. Efficient diode pump coupling occurs via the 6H15/2 4G11/2 absorption at 447nm. Slope efficiencies of 10% have been achieved in a non-optimal, free running, TEM00, resonator configuration. Results of Findlay-Clay and Laporta-Brussard laser analysis will be compared to laser spectroscopy and calorimetry measurements.

8381-57, Session 12

Nonlinear optical devices based on gallium nitride

S. R. Bowman, S. P. O'Connor, N. J. Condon, J. R. Meyer, I. Vurgaftman, C. R. Eddy, Jr., J. K. Hite, F. J. Kub, J. A. Freitas, Jr., U.S. Naval Research Lab. (United States)

Broadband transparency, high thermal conductivity, and strong nonlinearity make gallium nitride a promising material for high power frequency conversion. We have explored the potential of quasi-phase matched nonlinear devices based on this emerging material system. Lithographic patterning and MOCVD can generate patterned polarity-reversal films of GaN on bulk c-axis wafers. Rapid growth of these templates via HVPE can then produce high quality quasi-phase matching devices. We will review ongoing experiments on the material properties, fabrication issues, and projected performance of these novel nonlinear frequency converters.

8381-58, Session 12

Synthesis and spectroscopic properties of Er3+:Al2O3 ceramics

T. V. Sanamyan, R. Pavlacka, G. A. Gilde, M. Dubinskii, U.S. Army Research Lab. (United States)

Al2O3 (Sapphire) is an attractive material with thermal properties very favorable for high energy laser applications. Unfortunately, doping of this material with laser-active rare earth (RE3+) ions has always been a challenge due to significant ionic radius differences between the Al3+ site and RE3+ dopant. We report significant advances toward developing RE3+ doped Sapphire laser material based on our effort in material synthesis, combined with spectroscopic investigation of Er-doped Al2O3, powder and ceramic. Er:Al2O3 powder was synthesized by the co-precipitation and calcination of metal nitrate. Subsequently, Er:Al2O3 ceramic samples were produced via low temperature pressureless sintering of synthesized Er:Al2O3 powder. The results of spectroscopic investigations for a number of states of Er3+ ion in Er-doped Al2O3 ceramic are presented. The fluorescence lifetime for Er3+ 4I13/2 level was measured in a temperature range of 10 - 300K. The stimulated emission cross-section for 4I13/2 - 4I15/2 transition was inferred from fluorescence and excitation spectra using Fuchtbauer-Ladenburg relationship. The potential for laser action at room and cryogenic temperatures based on 4I13/2 - 4I15/2 transition is analyzed and presented.

8382-01, Session 1

Active and passive signatures in 2012

C. T. Hawley, National Signature Program (United States)

No abstract available

8382-02, Session 1

The U.S. Army Research Laboratory (ARL) multimodal signature database (MMSDB) advanced data storage solutions and security of data over the web

K. W. Bennett, U.S. Army Research Lab. (United States); J. Robertson, Clearhaven Technologies LLC (United States)

The U.S. Army Research Laboratory (ARL) archives vast amounts of data requiring a secure, portable file format along with a versatile software library for storing and accessing their data. Hierarchical Data Format 5 (HDF5) is a popular, general-purpose library, and open-source file format designed for archiving data, and providing extreme interoperability and data encryption for secure accessibility. Adding data encryption is of particular interest to many government agencies for the packaging and dissemination of datasets that may require differing levels of authorization and permissions. Individual dataset encryption within a single HDF5 file containing multiple datasets is theoretically possible, allowing several researchers with differing levels of permission to share a single HDF5 signature file. Encryption methodologies and technologies may benefit the limited distribution signatures process as well as being useful in sharing proprietary information amongst several contractors and government organizations and researchers. The process of easily integrating encryption methodologies into existing HDF5 interfaces requires additional research. This paper will provide an overview of the current state of effectively integrating encryption algorithms into HDF5 datasets along with possible applications, expectations, and limitations. Encryption algorithm examples using Java and MATLAB interfaces will provide several possible working solutions for implementation into the ARL Multimodal Signatures Database methodology for the dissemination of secure data over the Web. Finally, a discussion on enhancing the security of datasets stored in HDF5 will provide a framework for future enhancements and pathways to ultimate security of unclassified, but sensitive data over the Web.

8382-03, Session 1

An interactive 2D power-line modeling and simulation tool

R. N. Adelman, D. M. Hull, U.S. Army Research Lab. (United States)

The Army Research Laboratory's Power-Line UAV Modeling and Simulation (ARL-PLUMS) is a tool for estimating and analyzing quasi-static magnetic and electric fields due to power lines. This tool consists of an interactive 2-D graphical user interface (GUI) and a compute engine that can be used to calculate and visualize the E-Field and H-Field due to as many as seven conductors (two three-phase circuits and a ground wire). ARL-PLUMS allows the user to set the geometry of the lines and the load conditions on those lines, and then calculate Ey, Ez, Hy, or Hz along a linear path or cutting plane, or in the form of a movie. The path can be along the ground or in the air to simulate the fields that might be observed by an unmanned aerial vehicle (UAV), for example. In most cases, results are excellent, providing a "90% solution" in just a few minutes of total modeling and simulation time.

This paper will describe the physics used by ARL-PLUMS, including a 2-D Method of Moments solver. Examples of magnetic and electric fields for different wire configurations, including typical three-phase distribution and transmissions lines, will be provided. Comparisons to similar results using a full 3-D model will also be shown, and a discussion of errors that may be expected from the 2-D simulations will be provided. Additional features of the modeling and simulation tool (such as errors due to sensor noise, calibration, and cross-axis sensitivity) will be discussed as space permits.

8382-05, Session 2

Signatures of materials of interest using dielectric spectroscopy and statistical methodologies for classification

C. Gilbreath, U.S. Naval Research Lab. (United States); W. F. Brooks, Northrop Grumman Information Technology-TASC (United States)

No abstract available

8382-06, Session 2

Enhancing nuclear quadrupole resonance (NQR) signature detection leveraging subspace B-field interference suppression algorithms

W. Myrick, IvySys Technologies, LLC (United States); G. C. Gilbreath, J. B. Miller, U.S. Naval Research Lab. (United States)

Nuclear Quadrupole Resonance (NQR) is based on the interaction between radio frequency (RF) waves and nuclear spins associated with an explosive material of interest (MOI). The MOI is excited from an equilibrium state by RF waves at a particular frequency causing the MOI to emit NQR signatures. Since the emitted NQR signature has a weak free induction decay (FID) resulting from the RF wave excitation, detection with a unshielded magnetic sensor in the presence of RF interference occupying the same FID band is difficult. We explore leveraging commercial-off-the-shelf (COTS) B-field sensing equipment composed of multiple inexpensive antennas to improve the overall detection of the MOI while suppressing environmental interference. A description of the approach and processing architecture are presented based on COTS software defined radios (SDRs) and inexpensive B-field sensing antennas to support interference suppression with a high-Q antenna acting as both a transmit and receive antenna in an NQR spectrometry configuration. Subspace adaptive signal processing approaches are presented based on interference suppression architectures that extend to weak signal extraction of NQR based signature detection utilizing COTS sensing equipment.

8382-07, Session 2

Sensitivity characterization for low-frequency dielectric spectroscopy system electrodes

B. Bajramaj, U.S. Naval Research Lab. (United States); W. Myrick, IvySys Technologies, LLC (United States); C. Gilbreath, U.S. Naval Research Lab. (United States); J. Terosky, ITT Exelis (United States)

No abstract available

8382-08, Session 2

Neutron detection based on capture-gamma sensing and calorimetry

G. Pausch, C. Herbach, FLIR Radiation GmbH (United States); D. Mitchell, Sandia National Labs. (United States); R. Lentering, J. Stein, FLIR Radiation GmbH (United States)

Preventing illicit trafficking of radioactive material, in particular of Special Nuclear Material (SNM), is a major task with strong impact on homeland security. Passive radiation detectors developed for screening of passengers, vehicles, and cargo are looking for gamma and neutron signatures. The energy spectrum of gamma radiation bears a fingerprint of the source, which potentially allows discriminating threats against legal sources or naturally occurring radioactive materials. Neutron signals represent a distinctive signature of SNM. Radiation detection systems for security applications must therefore provide gamma spectroscopy and neutron detection capabilities. This is an economic challenge for two reasons: Gamma detectors of reasonable energy resolution are rather expensive; and He-3, the standard medium for neutron detection, has become a scarce good. Novel concepts combine neutron and gamma sensing in a single detector, thus reducing the overall expense. Low-cost converter media capturing thermal neutrons commute neutron flux in energetic gammas, which are then detected in a common gamma detector. Energy signals above ~3 MeV indicate neutron counts. Two prototype systems have been developed and tested: (1) The NCD, a 2"x2"x10" BGO scintillator with embedded Cd absorber sheets, demonstrated an intrinsic thermal-neutron detection efficiency of ~50%. (2) The PVTNG, comprising ~72 liters of PVT scintillator complemented with PVC panels, exhibited a neutron sensitivity of ~1.8 cps/ng, thus almost meeting the ANSI requirement for RPM. The spectroscopic performance turned out to be appropriate for nuclide identification. This is due to an unconventional detector construction combined with cutting-edge electronics, proper detector stabilization, and innovative calibration procedures.

8382-09, Session 2

Photofission signatures for the detection of highly enriched uranium

S. Pozzi, Univ. of Michigan (United States)

Linear-accelerator (LINAC) driven active interrogation systems are under increasing investigation as a means to detect nuclear materials which may be concealed in various types of shielding, as well as isotopes without significant passive neutron emissions; uranium-235 is one such isotope. Sufficient quantities of highly enriched uranium (HEU), for example, will generate a signal after interrogation has ceased (due to delayed neutron emission and subsequent fission reactions) whereas non-fissionable materials will not. However, delayed neutron emission is rare compared to prompt neutron emission and the delayed neutrons have a lower average energy. These properties make the measurement of prompt neutron emissions advantageous.

Prompt neutron emission during active interrogation is not unique to fissionable material; photoneutron reactions (gamma, xn) may also occur in common benign materials such as lead. Consequently, accurate simulation of the production and energy spectra of these prompt photoneutrons, as well as the detector response, is paramount in designing an effective interrogation system. Furthermore, the characteristics of the active-interrogation source must also be accurately modeled. Advanced Monte Carlo codes such as MCNPX-PoliMi are ideal for simulating all of these quantities. The presentation addresses LINAC-based systems interrogating HEU, depleted uranium, and lead. Discussion will include the simulated position of photonuclear events (gamma,fission, gamma,n and gamma,2n) and prompt neutron emissions from these events for several electron endpoint energies in the LINAC interrogating source.

8382-10, Session 2

Detection and identification of compound explosive using the SDA-method of the reflected THz signal

V. A. Trofimov, S. A. Varentsova, Lomonosov Moscow State Univ. (Russian Federation); N. Palka, T. Trzcinski, M. Szustakowski, Military Univ. of Technology (Poland)

We investigate the efficiency of spectral dynamics analysis (SDA) method for the detection of the explosive in the mixture of explosives. This problem did not investigate till present time. The detection occurs using the THz signal reflected from the substance. The main difficulty consists in complicated response of compound explosive: this response is not a sum of responses of separate explosives. Hence, to detect the features of each explosive is difficult problem. Using the spectrum as a tool of detection is not enough. For the detection and identification in this case, one needs to use the long time interval signal from the substance.

8382-11, Session 2

Resonance structure of water complexes of β-HMX for THz frequencies

L. Huang, U.S. Naval Research Lab. (United States); A. Shabaev, George Mason Univ. (United States); S. Lambrakos, N. Bernstein, V. L. Jacobs, U.S. Naval Research Lab. (United States); L. Massa, Hunter College (United States)

THz excitations are characteristically slow molecular states, in contrast to excitations that can induce electronic state transitions. Owing to the perturbative character of THz excitations, detection methodologies can be developed which do not damage materials. In addition, the perturbative character of THz excitation has significant implications with respect to its simulation using density functional theory (DFT).

A significant aspect of using response spectra calculated by DFT, for the direct construction of dielectric response functions, is that it adopts the perspective of computational physics, according to which a numerical simulation represents another source of "experimental" data. A general procedure may be developed for construction of dielectric response functions using DFT calculations as quantitative estimates of spectral response features for subsequent adjustment with respect to additional information such as experimental measurements and theory based calculations. DFT has been successfully applied to investigate response spectra of single molecules and molecular crystals.

The vibrational spectra of water complexes of explosive molecules are characteristically different from those of single molecules. Most importantly, the response spectra of explosive molecules are typical of what would be detected in practice for explosives detection in the presence of humidity. Presented are DFT calculations of ground state resonance structure of water complexes of beta-HMX. These are the ground state molecular geometries and response spectra for water complexes. These spectra are used to construct parameterized permittivity functions.

8382-12, Session 3

Data dependency on measurement uncertainties in speaker recognition evaluation

J. C. Wu, A. Martin, C. Greenberg, R. Kacker, National Institute of Standards and Technology (United States)

The National Institute of Standards and Technology (NIST) conducts an ongoing series of Speaker Recognition Evaluations (SRE). Speaker detection performance is measured using a detection cost function defined as a weighted sum of the probabilities of type I error and of type II error. The sampling variability can result in measurement uncertainties. Thus, the uncertainties of the detection cost functions must be taken into consideration in SRE. In our prior study, the data independence was assumed while applying the nonparametric two-sample bootstrap methods based on our extensive bootstrap variability studies on large datasets to compute the standard errors (SE) of detection cost functions. In this article, the data dependency caused by multiple usages of the same subjects is taken into account. Hence, the data are grouped into target sets and non-target sets, and each set contains multiple scores. One-layer and two-layer bootstrap methods are proposed based on whether the two-sample bootstrap resampling takes place only on target sets and non-target sets, respectively, or subsequently on target scores and non-target scores within the sets. The SEs of the detection cost function using these two methods along with those with the assumption of data independency are compared. It is found that the data dependency increases both estimated SEs and the variations of SEs. Thus, in order to obtain more accurate measures in SRE, the data should be sampled randomly. Based on our research, some suggestions regarding the test design are provided.

8382-13, Session 3

Speckle signatures of articulating humans

D. G. Conrad III, Univ. of Dayton (United States); E. A. Watson, Air Force Research Lab. (United States)

Speckle is a well-investigated interference phenomenon that is produced by coherent light scattering off a rough surface. While speckle is often considered a noise source, it can be used to obtain information about the object. We investigate a non-imaging technique using speckle statistics to estimate object articulation. It is known that the speckle irradiance in the far field depends on two factors: the illumination distribution at the object and the field correlation properties of the materials composing the object. It is anticipated that as an object articulates, perhaps periodically as in a person walking, the object illumination distribution, and therefore average speckle size in the far field, will vary in time. An estimate of the time variation of the average speckle size can then be used to estimate the motion of the object. In this paper we investigate, through simulation and lab experiments, the effect of object articulation on speckle statistics. We find that the motion of a person walking will produce a measurable variation in speckle statistics (field correlation function) and that the correlation function can be estimated from a single speckle realization.

8382-14, Session 3

The use of skin reflectivity data to determine the optimal site and wavelength to collect human vital sign signatures

K. A. Byrd, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The radial (carotid) artery has been used extensively by researchers to demonstrate that Laser Doppler Vibrometry is capable of exploiting vital sign signatures from cooperative human subjects. Research indicates that, the carotid, although good for cooperative and non-traumatic scenarios, is one of the first vital signs to become absent or irregular when a casualty is hemorrhaging and in progress to circulatory (hypovolemic) shock. In an effort to determine the optimal site and wavelength to measure vital signs off human skin, a human subject data collection was executed whereby 14 subjects had their skin reflectivity and vital signs measured at five collection sites (carotid artery, chest, back, right wrist and left wrist). In this paper, we present our findings on using LDV and reflectivity data to: 1) correlate maximum levels of reflectivity with vital sign signal levels collected at three ranges, 2) analyze the accuracy of vital sign measurements made from humans subjects wearing retroreflective tape vs. not wearing retroreflective tape, and 3) provide a mathematical characterization of vital sign signal degradation as a function of range.

8382-15, Session 4

Signatures of explosives and precursors at deep ultraviolet to near-infrared wavelengths

J. Grun, R. Lunsford, S. Nikitin, U.S. Naval Research Lab. (United States)

No abstract available

8382-16, Session 4

Dependence of observed resonance Raman intensities of energetic materials on their Raman cross sections

S. A. Asher, L. Wang, M. K. Ghosh, Univ. of Pittsburgh (United States)

Standoff Raman detection of explosives and other threat chemical and biological species requires maximizing the spectral signal-to-noise ratios (S/N). This requires maximizing the intensity of the analyte signals while minimizing that of interferents and that of backgrounds. This optimization can be accomplished by deep UV resonance Raman excitation that simultaneously increases the Raman cross sections, increases the spectral selectivity and avoids relaxed fluorescence interference. Unfortunately, the intensity is attenuated by self absorption. We will discuss the dependence of the observed intensities and spectral S/N in standoff detection of resonance Raman spectra of energetic molecules on these phenomena and the trade-offs required to maximize spectral S/N.

8382-18, Session 4

Opposition effect spectropolarimetry in the visible and near-infrared

K. Foster, G. Cervone, George Mason Univ. (United States); R. G. Resmini, The MITRE Corp. (United States)

Observations of particulates with small source-target-sensor angles (< 5 deg.) can reveal polarized reflectances. A VNIR hyperspectral imager is outfitted with a rotatable linear polarization filter and used to generate Stokes cubes at key geometries. A study is performed to determine the extent to which these polarized reflectances can be exploited in differentiating between particulate samples scattered on a particulate substrate material, an idea for which preliminary results indicate some merit.

8382-19, Session 4

Study of hyperspectral characteristics of different types of flares and smoke candles

P. Lagueux, V. Farley, M. Chamberland, Telops (Canada); M. Kastek, T. Piatkowski, R. Dulski, Military Univ. of Technology (Poland)

Modern infrared camouflage and countermeasure technologies used in the context of military operations have evolved rapidly over the last decade. Indeed, some infrared seekers and decoy/flares tend to have spectral sensitivity tailored to closely match the emission signatures of military vehicles (such as aircrafts, tanks) and reject other sources. Similarly, some candles (or smoke bombs) are developed to generate large area screens with very high absorption in the infrared.

The Military University of Technology has conducted an intensive field campaign where various types of flares and smoke candles were deployed in different conditions and measured. The high spectral, spatial

and temporal resolution acquisition of these thermodynamic events was recorded with the Telops Hyper-Cam.

The Hyper-Cam enables simultaneous acquisition of spatial and spectral information at high resolutions in both domains. The ability to study combustion systems with high resolution, co-registered imagery and spectral data is made possible.

This paper presents the test campaign concept and definition and the analysis of the recorded measurements.

8382-20, Session 4

Multispectral and hyperspectral measurements of soldier's camouflage equipment

M. Kastek, Military Univ. of Technology (Poland); P. Lagueux, Telops (Canada); T. Piatkowski, Military Univ. of Technology (Poland); M. Chamberland, Telops (Canada); R. Dulski, Military Univ. of Technology (Poland); V. Farley, Telops (Canada)

In today's electro-optic warfare era, it is more than vital for one nations' defence to possess the most advanced measurement and signature intelligence (MASINT) capabilities. This is critical to gain a strategic advantage in the planning of military operations and deployments.

The thermal infrared region of the electromagnetic spectrum is one of the key regions that is exploited for infrared reconnaissance and surveillance missions.

The Military University of Technology has conducted an intensive measurement campaign of various soldier's camouflage devices in the scope of building infrared signature database. One of today's key required technologies to perform signature measurements has become infrared hyperspectral and broadband/multispectral imagers.

The Telops Hyper-Cam LW product represents a unique commercial offering with outstanding performances and versatility for the collection of hyperspectral infrared images. The Hyper-Cam allows for the infrared imagery (320 x 256 pixels) at a very high spectral resolution (down to 0.25 cm-1). Moreover, the Military University of Technology has made use of a suite of scientific grade commercial infrared cameras to further measure and assess the targets from a broadband/multispectral perspective.

The experiment concept and measurement results are presented in this paper.

8382-21, Session 4

Blind separation of human- and horse-footstep signatures using independent component analysis

A. Mehmood, U.S. Army Research Lab. (United States)

Seismic footstep detection based systems for homeland security applications are important to perimeter protection and other security systems. This paper reports seismic footstep signal separation for a walking horse and a walking human. The well-known Independent Component Analysis (ICA) approach is employed to accomplish this task. ICA techniques have become widely used in audio analysis and source separation. The concept of ICA may actually be seen as an extension of the principal component analysis (PCA), which can only impose independence up to the second order and, consequently, defines directions that are orthogonal. They can also be used in conjunction with a classification method to achieve a high percentage of correct classification and reduce false alarms. In this paper, an ICA based algorithm is developed and implemented on seismic data of human and horse footsteps. The performance of this method is very promising and is demonstrated by the experimental results.

8382-22, Session 4

Analysis of electrostatic charge on small-arms projectiles

S. Vinci, D. M. Hull, J. Zhu, U.S. Army Research Lab. (United States)

Triboelectric (frictional) and combustion processes impart electrostatic charge on projectiles as they are fired. Additional charging and discharging processes alter the magnitude of charge in-flight, and are complex functions of a plethora of environmental conditions. There is an interest in using electric-field sensors to help detect and track projectiles in counter-sniper and projectile ranging systems. These applications require knowledge of the quantity of charge, as well as the sensitivity of electric field sensors.

The U.S. Army Research Laboratory (ARL) took part in multiple experiments at Aberdeen Proving Grounds (APG) to simulate a battlefield-like environment. Sensors were placed in strategic locations along the bullets' paths and recorded electric-field signatures of charged small-arms bullets. The focus of this effort was to analyze the electric-field signatures collected during the APG experiment in order to estimate electrostatic charge on the bullets. Algorithms were written to extract electric-field bullet signatures from raw data; these signatures were further processed to estimate range, speed, and charge. These estimates were compared to similar estimates from acoustic signatures for verification. Ground-truth GPS data was used to calculate ranges, azimuths, and miss distances. Signatures were filtered to remove clutter signals from power lines and other unwanted field sources. Closed-form equations were then fitted to the collected signatures, to retrieve estimates for the magnitude of charge on the bullets.

Test data, collected with sensors placed on a wall, showed enhanced e-field intensity. A Method of Moments (MoM) model of the wall was created to improve signature simulation. Detectable charges on bullets were found to exist in the 10-10 C to 10-12 C range. Relationships between estimated charge, gun type, bullet caliber, noise thresholds and number of shots in sequence are presented and statistically analyzed.

8382-23, Session 5

Clairvoyant fusion methods of detection applied to dielectric spectroscopy

A. P. Schaum, U.S. Naval Research Lab. (United States); B. T. Williams, Space and Naval Warfare Systems Ctr. Pacific (United States); D. Robinson, TASC, Inc. (United States)

No abstract available

8382-24, Session 5

Tripod operators for efficient search of point cloud data for known surface shapes

F. Pipitone, U.S. Naval Research Lab. (United States)

No abstract available

8382-25, Session 5

Acoustic change detection algorithm using an FM radio

G. H. Goldman, O. Wolfe, U.S. Army Research Lab. (United States)

There is interest in developing low cost, low power, non-line-of-sight sensors for monitoring human activity. One modality that is often

overlooked is active acoustics using sources of opportunity such as speech or music. Active acoustics can be used to detect human activity by generating acoustic images of an area at different times then testing for changes among the imagery.

This paper will describe and report test results for an algorithm that can detect a physical change in a building such as a door changing positions or a large box being moved. First, the area will be illuminated with sound and acoustic data will be collected with two or more microphones. Next, the spectrum of the acoustic data collected at two different times is equalized. Then, range profiles of the acoustic reflectivity are generated at each time interval, subtracted, and their differences are normalized. Detection occurs when the energy of the normalized difference is greater than a threshold determined using a Student's t-test.

The algorithm was tested using a transistor radio as the source and two microphones placed in the hallway as the sensors. The algorithm successfully detected a change in the position of a door in a hallway using 20 second intervals of data.

8382-26, Session 6

Characterization of the atmosphere as a random bit-stream generator

C. O. Font, D. Bonanno, C. Gilbreath, B. Bajramaj, U.S. Naval Research Lab. (United States)

Characterizing atmospheric turbulence through modeling dates back to the 1960's. For decades scientists have study how to mitigate the effects of the atmospheric turbulence on communications and imaging systems, but learning how to use those properties of the atmosphere instead of mitigate them raise new challenges. Due to the fact that atmospheric turbulence is inherently a random process, it can be an ideal "key generator" for strongly secure information transfer. The purpose of this effort is to investigate until which extend the atmospheric turbulence can be exploited as a robust random number generator. In this paper we report the progress in characterizing the atmosphere and a random bit-stream generator.

8382-27, Session 6

High-power, high-resolution imaging radar: detection and characterization advances via coherent uplink array techniques applied to space situational awareness

B. Geldzahler, R. McGinnis, J. Crusan, NASA Headquarters (United States); K. B. Fielhauer, D. P. Watson, Johns Hopkins Univ. Applied Physics Lab. (United States); C. Moulton, G. Ushomirsky, MIT Lincoln Lab. (United States)

NASA is currently investigating architecture and technology options to include a high power, high resolution radar system for Near Earth Objects (NEO), orbital debris, and space situational awareness studies. Key to the future architecture of the radar system are technologies that will enable capability and performance enhancement of orders of magnitude while at the same time improving the operability and decreasing the operations and maintenance costs of the current system. One technology and architecture being investigated by NASA, and publicly discussed by NASA and Jet Propulsion Laboratory personnel in peer-reviewed publications, is the potential of large distributed phased arrays of small aperture antennas at Ka band with real-time compensation for atmospheric fluctuations. Such a technology has already been demonstrated at lower frequencies and, if demonstrated to be viable at Ka band, could yield resolution increases of 100x-1000x while significantly decreasing operations costs for radar as a whole. NASA's current plans for such a demonstration will be presented.

8382-28, Session 6

Extension of coherent uplink arraying to high frequency: the New York New York demonstration

K. M. Minear, G. P. Martin, Harris Corp. (United States)

No abstract available

8382-29, Session 6

The NASA uplink arraying test bed: implementation at Kennedy Space Center

M. Seibert, NASA Glenn Research Ctr. (United States); M. Miller, P. Aragona, NASA Headquarters (United States)

No abstract available

8382-30, Poster Session

Quantum Raman spectroscopy

M. O. Lanzagorta, ITT Exelis (United States)

Raman spectroscopy is an important tool to determine the vibrational, rotational, and any other low-frequency modes in a molecular system. This technique has the potential application of detecting biological and chemical agents in the atmosphere. Raman spectroscopy is based on the measurement of those photons that undergo inelastic scattering with molecules. That is, the energy of the incoming and scattered photons is different. This is in contrast to Rayleigh scattering, where the incident and scattered photons have the same energy. It is easy to show that the Rayleigh scattering cross section is much larger than the Raman scattering cross section, by a factor proportional to the number of scattering molecules in the testing sample. As a consequence, Raman spectroscopy suffers from low signal-to-noise ratio (SNR). Previous research efforts have shown that the use of a pair of entangled photons could improve the SNR for Raman spectroscopy. In this paper we will present a general framework based on quantum electrodynamics that describes Raman spectroscopy using an arbitrarily large number of entangled photons. Our objective is to analyze Raman spectroscopy as a quantum information channel and study its asymptotic limits. In particular, if we consider quantum entanglement as an information resource, then the use of entangled photons offers an exponentially large improvement on the sensitivity of the Raman spectrograph. That is, the correlations embedded in quantum entanglement can be exploited to enhance the Raman signature of the tested samples.

Conference 8383A: Head- and Helmet-Mounted Displays XVII: Design and Applications

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8383A-01, Session 1

Novel HMD concepts from the DARPA SCENICC program

R. Sprague, MicroVision, Inc. (United States)

Access to digital information is critical to modern defense missions. Sophisticated sensor systems are capable of acquiring and analyzing significant data, but ultimately this information must be presented to the user in a clear and convenient manner. Head-worn displays (HWDs) offer one means of providing this digital information. Unfortunately, conventional HWDs occupy significant volume and have serious performance limitations. To truly offer a seamless man/machine interface, the display must be able to provide a wide array of information in a manner that enhances situation awareness without interfering with normal vision. Providing information anywhere in the eye's field of view at resolutions comparable to normal vision is critical to providing meaningful information and alerts. Furthermore, the HWD must not be bulky, heavy, or consume significant power. Achieving these goals of the ideal wearable display has eluded optical designers for decades. This paper discusses the novel approach being developed under DARPA's SCENICC program to create a high resolution HWD based on using advanced contact lenses. This approach exploits the radically different concept of enhancing the eye's normal focus accommodation function to enable direct viewing of high resolution, wide field of view transparent image surfaces placed directly in front of the eye. Integrating optical components into contact lenses eliminates all of the bulky imaging optics from the HWD itself creating a high performance wearable display in a standard protective eyewear form factor. The resulting quantum advance in HWD performance will enable HWD's to expand well beyond their current limited rolls.

8383A-02, Session 1

Scorpion HMCS developmental and organizational flight test status and results

R. Atac, Gentex Corp. (United States)

Gentex Corporation is nearing completion of the developmental and operational test phase of the Helmet Mounted Integrated Targeting (HMIT) contract with the Air National Guard and Air Force Reserve. HMIT program involves qualification and installation of the Scorpion HMCS Color HMD in both the A-10C and F-16C Block 30 aircraft types. Both aircraft types are flying and have had excellent results. This paper discusses the program status and results, as well as a number of new developments in regard the Scorpion HMCS program.

8383A-03, Session 1

Advanced Helmet Vision System (AHVS) integrated night vision HMD

T. Ashcraft, R. Atac, Gentex Corp. (United States)

Gentex Corporation, under contract to Naval Air Systems Command AIR 4.0T, has designed the Advanced Helmet Vision System to provide aircrew with 24-hour, visor-projected binocular night vision and HMD capability. The AHVS project involves integration of numerous key technologies, including very high brightness LED-based digital light engines, advanced lightweight optical materials and manufacturing processes, and innovations in graphics processing software. This paper reviews the current status of miniaturization and integration with the latest two-part Gentex modular aircrew common helmet (MACH), highlights the lessons learned from previous AHVS phases, and discusses plans for qualification and flight testing.

8383A-04, Session 1

Soldier-worn augmented reality system for tactical icon visualization

D. C. Roberts, S. Snarski, T. Sherrill, A. Menozzi, B. Clipp, P. Russler, Applied Research Associates, Inc. (United States)

This paper describes the development and testbed demonstration of a soldier-worn augmented reality system that provides intuitive 'heads-up' visualization of tactically-relevant geo-registered icons. Our system combines a robust soldier pose estimation capability with a helmet mounted see-through display to accurately overlay geo-registered iconography (i.e., navigation waypoints, targets, blue forces, aircraft assets, and weapons effects) on the soldier's view of reality. Applied Research Associates (ARA), in partnership with BAE Systems and the University of North Carolina - Chapel Hill (UNC-CH), has developed this system in Phase 2 of the DARPA ULTRA-Vis (Urban Leader Tactical, Response, Awareness, and Visualization) program.

The ULTRA-Vis system is robust to magnetic disturbances and requires no a priori mapping of the environment. We achieve accurate and robust pose estimation through fusion of inertial, magnetic, GPS, and computer vision data acquired from helmet kit sensors. Icons are rendered on a high-brightness, 40°x30° field of view see-through display. The system incorporates an information management engine to convert CoT (Cursor-on-Target) external data feeds into mil-standard icons for visualization. The user interface provides intuitive information display to support soldier navigation and efficient communication of tactical information to external sources.

In this paper, we report on testbed system performance for a broad range of outdoor operational conditions, including the presence of magnetic disturbances, highly-dynamic user head motions, and low-light conditions. Throughout Phase 2, we have interfaced with the soldier user community to align system functionality with military CONOPS. In future work, we will enhance the soldier user interface, add capabilities for GPS-degraded operation, and reduce system size, weight, and power to support extended field trials.

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8383A-05, Session 1

Critical testing for helmet-mounted displays: a tracking system accuracy test for the Joint Helmet Mounted Cueing System

A. Renner, Air Force Research Lab. (United States)

It is common for electronics and software to evolve over the lifecycle of any aircraft system due to requirements changes or diminishing manufacturing sources. Hardware and software bugs are often introduced as the design evolves and it is necessary to re-validate a systems performance attributes over the course of these design changes. Helmet Mounted Displays (HMDs) have not been supported with adequate methods and materials to address this need, specifically in regards to the validation and verification of the underlying tracking

systems when tested in a simulated or operational environment. An on-aircraft test has been developed and refined to address this testing gap for the Joint Helmet Mounted Cueing System (JHMCS) on F-16 aircraft. This test can be readily ported to other aircraft systems which employ the JHMCS, and has already been ported to the F-18. Additionally, this test method could provide an added value in the testing of any HMD that requires accurate cueing, whether used on fixed or rotary wing aircraft.

8383A-06, Session 2

Designing the HMD for perfection: a look at the human eye

P. R. Havig II, J. P. McIntire, E. E. Geiselman, Air Force Research Lab. (United States)

As we near the ability in microdisplays to surpass the resolution of the human eye it is worth reviewing this remarkable sensor to better understand where future needs may be. In this paper we review the human eye and then compare current and future trending applications for helmet mounted displays. We aim to show best practices for development of new and innovative displays that work with the human rather than against the human.

8383A-07, Session 2

Ergonomic design considerations for an optical data link between a warfighter's head and body-worn technologies

N. Trew, G. Burnett, M. Sedillo, C. S. Washington, Air Force Research Lab. (United States); A. Linn, Ball Aerospace & Technologies Corp. (United States); Z. Nelson, Oak Ridge Institute for Science & Education (United States)

No abstract available

8383A-08, Session 2

Systems engineering considerations in body-mounted sensing

P. L. Marasco, Air Force Research Lab. (United States)

The desire to augment human performance with additional information and sensing capabilities remains great and is perhaps becoming even more desirable as witnessed by the recent initiation of a few large technology development programs. Considerable advances have been made recently on focal planes that could possibly be used in body-mounted sensing. Advances in optical technology yielded the potential for lighter and smaller objective and eyepiece lenses. While display technology development has lagged somewhat, recent advances have made available displays that were unimaginable only a few years ago. However, the systems engineering implications of these new focal planes, optics, displays, and performance augmentation technologies have not been adequately examined. This paper will present one possible human factors based systems architecture to examine engineering trades in body-mounted sensing. Issues such as sensor and display resolution, the use of color, body supported loads, power, processing and computational power, along with offensive and defensive capabilities will be considered. A case for the replacement of traditional, piece-wise system development with integrated body-mounted system development will also be presented.

8383A-09, Session 3

How microdisplays enable today's and tomorrow's military vision systems

J. Carollo, eMagin Corp. (United States)

No abstract available

8383A-10, Session 3

A 5.6Mdot OLED microdisplay for digital night vision and image fusion

G. Haas, L. Espuno, E. Marcellin-Dibon, C. Prat, MicroOLED (France)

Digital night vision systems are attractive over image intensifier tubes, as they provide digital video processing e.g. for noise reduction or contrast enhancement, as well as displaying additional information as e.g. graphical overlays, or displaying fused images e.g. by overlaying to the night vision image the image from an IR sensor. However, current systems suffer from disadvantages like high power consumption, low resolution, and time lag.

In order to help overcoming these problems, we developed a 0.61" diagonal OLED microdisplay with very high resolution, excellent image quality, low power consumption, and a user friendly digital interface. The pixel matrix consists of 5.4 million subpixels arranged in a so called QUAD arrangement. The subpixel pitch is 4.7x4.7µm², which to our knowledge is the finest in the world for this type of display. The display also integrates a 10bit digital video interface as well as a digital control interface.

In a full color version, 4 subpixels are grouped together using RGB color filters, resulting in a resolution of 1300x1048 pixels (SXGA + 20 extra lines and columns). In a monochrome version (white or green), all subpixels can be addressed independently, resulting in a resolution of 2600x2088 pixel, which enables for instance digital night vision at full 2K by 2K resolution. Some of the characteristics that could be obtained are:

- Contrast of 100.000:1
- Spatial Uniformity: 96%, with no visible fix pattern
- Power consumption about 200mW, including digital interface
- Luminance: <1cd/m² up to 10000cd/m²

8383A-11, Session 3

Active-matrix, organic-light-emitting diode (AMOLED)-XL performance and life test results

D. A. Fellowes, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The US Army and eMagin Corporation established a Cooperative Research and Development Agreement (CRADA) to characterize the ongoing improvements in the lifetime of OLED displays. This CRADA also called for the evaluation of OLED performance as the need arises, especially when new products are developed or when a previously untested parameter needs to be understood. In 2006, eMagin Corporation developed long-life OLED-XL devices for use in their AMOLED microdisplays for head-worn applications. Through Research and Development programs from 2007 to 2011 with the US Government, eMagin made additional improvements in OLED life and developed the first SXGA (1280 X 1024 triad pixels) and WUXGA (1920 X 1200) OLED microdisplays. US Army RDECOM CERDEC NVESD conducted life and performance tests on these displays, publishing results at the 2007, 2008, 2009, 2010, and 2011 SPIE Defense, Security and Sensing Symposia. Life and performance tests have continued through 2011, and this data will be presented along with a recap of previous data. This

should result in a better understanding of the applicability of AMOLEDs in military and commercial head mounted systems: where good fits are made, and where further development might be desirable.

8383A-12, Session 3

Design considerations of HUD projection systems applied to automobile industry

J. A. Betancur Ramírez, Univ. EAFIT (Colombia)

Currently, the topics about HUD systems are strongly going inside on the automobile industries; consequently, there have been proposed new ways to understand and apply this technology in an economically viable way. To contribute to this situation, this paper presents a case study which sets out key parameters that should be considered on the design of an HUD, how can be configured these parameters, and how they are related. Finally, it is presented an optical design alternative that meets the main requirements of an HUD system applied to mid-range automobiles. There are several ways to cover the development and construction of HUD systems, the method here proposed is raised to provide and to understand the factors involved in this technology and the popularization of it on the automobile industry.

8383A-13, Session 3

Optical waveguide technology and its application in head-mounted displays

A. A. Cameron, BAE Systems (United Kingdom)

Applying optical waveguide technology to head mounted display (HMD) solutions has the key goal of providing the user with improved tactical situational awareness by providing information and imagery in an easy to use form which also maintains compatibility with current night vision devices and also enables the integration of future night vision devices. The benefits of waveguide technology in HMDs have seen a number of alternative waveguide display technologies and configurations emerge for Head mounted Display applications. BAE System presented one such technology in 2009 and this is now in production for a range of Helmet Mounted Display products.

This paper therefore, outlines the key design drivers for aviators Helmet Mounted Displays, provides an overview of holographic Optical Waveguide Technology and its maturation into compact, lightweight Helmet Mounted Displays products for aviation and non-aviation applications. Waveguide displays have proved too be a radical enabling technology which allows higher performance display devices solutions to be created in a revolutionary way. It has also provided the user with see through daylight readable displays, offering the combination of very large eye box and excellent real world transmission in a compact format.

8383A-14, Session 4

HMDs as enablers of situation awareness, the OODA loop and sense-making

J. E. Melzer, Rockwell Collins Optronics (United States)

Helmet-Mounted Displays (HMDs) have been shown to be powerful tools in unlocking the pilot from the interior of the cockpit or the forward line of sight of the Head-Up Display. Imagery that is presented in one of three reference frames can enable the pilots to do their job more effectively while simultaneously decreasing workload. This paper will review key attributes Situation Awareness, the Observe/Orient/Decide/Act (OODA) Loop and Sense-making and how HMDs aid the pilot in achieving these ideal cognitive states.

8383A-15, Session 4

Rotary wing brown-out symbology: what's the advantage of conformality?

S. A. Jennings, National Research Council Canada (Canada)

No abstract available

8383A-16, Session 4

Making the case for off-axis ownship attitude symbology: we may not miss it until it's not there

E. E. Geiselman, P. R. Havig II, Air Force Research Lab. (United States)

Much research work has been completed over the past decades indicating that the use of Helmet-Mounted Displays (HMDs) in a tactical aircraft application results in significant pilot behavior changes. Specifically, with off-axis availability of targeting symbology via an HMD, pilots' line-of-sight excursion is farther off axis for longer periods of time than during performance of the same task absent the availability of off-axis information. This tends to be true regardless of the presence of ownship attitude information (OAI) on the HMD. There has been significant research completed attempting to optimize the portrayal of OAI via the HMD and, there has simultaneously been resistance by the user community regarding the inclusion of OAI. The stated reason is usually because they find it unnecessary. This paper includes a review of both sides of this discussion and attempts to make the case that, similar to the evolution of the Head-Up Display (HUD) as a primary flight reference, there are likely operational performance and safety-of-flight reasons to justify off-axis OAI within even limited field-of-view applications. This may be especially true in the case of a HUD-less cockpit.

8383B-02, Session 1

Impediments to the rapid insertion of innovative displays and peripherals

G. M. Nicholson, Naval Surface Warfare Ctr. Crane Div. (United States)

In order to optimize system performance and minimize cost for a system to fill capability gaps, an improvement to rapid insertion of innovative display and peripheral technology is required to take advantage of human-machine intersections. Current approaches to testing and integration impedes successful rapid insertion of innovative technology for new systems and incremental upgrades. Considerations to innovative displays and peripherals must occur further to the left of the lifecycle to be successful and key integration areas must be address for success. A scenario of rapid insertion of an Helmet Mounted Display (HMD) is outlined as an example of these issues.

8383B-09, Session 1

Evaluation of a 15-inch widescreen OLED with sunlight-readable resistive touch

J. Tchon, B. Hufnagel, Rockwell Collins, Inc. (United States)

A commercially available 15-inch television using an active-matrix organic light-emitting diode display (AMOLED) was modified to include a sunlight-readable resistive touch panel for technical evaluation with regard to a variety of rugged military and aerospace applications. OLEDs emit un-polarized light but are highly reflective and so often include a circular polarizing (CP) film on the front surface to reduce ambient reflection. Sunlight-readable resistive touch panels also include CP so, in theory, one set is redundant. By removing the CP from the AMOLED and relying on the touch panel's CP, the authors were able to minimize change in display luminance while adding touch capability and reducing reflectance.

Display performance was assessed for several configurations. Beside the original AMOLED performance with its native CP film, we measured specular and diffuse reflectance for these additional configurations: without native CP film, with a commercial off-the-shelf (COTS) film-glass type sunlight readable touch panel, with a modified COTS film-glass replacing the front low-reflectance film with both anti-reflection and anti-reflection with anti-glare, and a COTS glass-glass touch panel modified with our own CP film for lowest possible haze. Included is a brief discussion on trades between bonded touch panel thickness and speckle, haze and effects of apparent depth to the image plane.

Also explored is the effect on luminance and chromaticity over angle and how this compares to similar touch panel configurations based on liquid crystal displays having polarized light output and the necessity of adding an additional quarter-wave retardation film. However, aside from the problem of differential color aging in AMOLED displays, high luminance and being able to maintain stable luminance across temperature, life and video content continues to be a source of concern. Strengths and weaknesses of OLEDs and LCD as they relate to the evaluation are discussed.

8383B-03, Session 2

An electronic flight bag for NextGen avionics

E. Zelazo, Astronautics Corp. of America (United States)

The introduction of the Next Generation Air Transport System (NextGen) initiative by the Federal Aviation Administration (FAA) will impose new requirements on cockpit avionics. NextGen will require aircraft to utilize Automatic Dependent Surveillance-Broadcast (ADS-B) in/out technology, requiring substantial changes to existing cockpit display systems. Rather than bearing the burden of purchasing new primary flight displays to replace older, incompatible ones, a more cost-effective solution is available. Providing an advanced class 3 Electronic Flight Bag (EFB), in lieu of replacing existing displays, can simplify the time of implementation for many users at a substantially lower cost. This paper describes a Class 3 EFB, called the Nexis Flight-Intelligence System, that has been designed to allow users a direct interface with NextGen avionics sensors while additionally providing the pilot with all the necessary information to meet NextGen requirements.

8383B-04, Session 2

An avionics touch screen-based control display concept

M. Mertens, Barco N.V. (Belgium); H. J. Damveld, Technische Univ. Delft (Netherlands)

The Control Display Unit (CDU) serves as the main input device for the Flight Management System (FMS), and is used frequently in the planning phase before departure and arrival. Traditionally, the CDU has a limited, text only, display for feedback of the textual input. The effects of the CDU inputs, for instance on the planned route, are visualized on other displays, such as the navigation (NAV) or multifunction (MFD) display, and are depending on the selected display mode. The strict separation between input and output, in combination with the sometimes cumbersome keyboard-based CDU input, has already led to accidents such as American Airlines Flight 965.

A hardware prototype of a multi-touch Touch Screen Control Unit (TSCU) was developed to allow for a more intuitive and efficient FMS interface in the cockpit. This unit is a CDU format unit and consists of a display and touch overlay over the full size of the unit.

A graphical software application was developed to perform the same operations that can be performed with the route (RTE) and route legs (RTE LEGS) pages of a conventional CDU, but now using a Direct Manipulation Interface (DMI) of the displayed graphics. The DMI ensures that the pilot's input operates directly on the desired part of the route, and prevents many unwanted operations. During the design of the DMI, special attention was given to select the appropriate touch gestures for the required operations.

The TSCU can also be switched to a virtual CDU mode, where a conventional virtual keyboard is displayed that can be commanded with the touch interface. As such the unit can be a drop in replacement for a legacy CDU. In addition, the TSCU could be used for a variety of other cockpit functions such as: flight planning, cursor control, charts, radio management, ... This results in a more efficiënt usage of board space and a reduction of real estate and thus cost.

This paper will highlight the physical hardware of the realized prototype and the SW defined applications.

8383B-05, Session 2

Display challenges resulting from the use of WFOV imaging devices

G. J. Petty, E. J. Seals, J. E. Fulton, Jr., G. M. Nicholson, Naval Surface Warfare Ctr. Crane Div. (United States)

As focal plane array technologies advance and imagers increase in

resolution, display technology must outpace the imaging improvements in order to adequately represent the complete data collection. Typical display devices tend to have an aspect ratio similar to 4:3 or 16:9, however a breed of Wide Field of View (WFOV) imaging devices exist that skew from the norm with aspect ratios as high as 5:1. This particular quality, when coupled with a high spatial resolution, presents a unique challenge for display devices. Standard display devices must choose between resizing the image data to fit the display and displaying the image data in native resolution and truncating potentially important information. The problem compounds when considering the applications; WFOV high-situational-awareness imagers are sought for space-limited military vehicles. Tradeoffs between these issues are assessed to the image quality of the WFOV sensor.

8383B-07, Session 2

A high-performance approach to minimizing interactions between inbound and outbound signals in helmet

C. Kwan, J. Zhou, B. Ayhan, Signal Processing, Inc. (United States); S. Sands, NASA Glenn Research Ctr. (United States)

In this paper, we will present the following results. First, we present a Matlab based simulation tool to emulate inbound and outbound signal interactions. The tool can emulate reverberant conditions. Three time-domain adaptive filters (least mean square (LMS), affine projection (AP), and recursive least square (RLS)) were applied to remove inbound signals from outbound signals. Based on the simulation results, it was found that RLS yielded the best performance. However, RLS is the most computationally intensive one. Second, we performed actual experiments under three scenarios: office, bowl, and helmet. Here, in addition to the 3 adaptive filters mentioned earlier, we also developed a new frequency domain adaptive filter called FDAFSS (frequency domain adaptive filter with spectral subtraction). FDAFSS is compared with LMS, AP, and RLS filters and FDAFSS yielded better performance. Moreover, FDAFSS is fast and can yield uniform convergence across different frequency bands. Third, encouraged by the performance of FDAFSS, we developed another novel adaptive filter in the frequency domain, which can suppress inbound signal, deal with reverberation, and eliminate background noise. This novel algorithm is motivated by Wiener filter and is called MSE-RC (mean square error with reverberation compensation). We applied this MSE-RC algorithm to the experimental data and found that it yielded the best performance. The perceptual speech quality (PESQ) reached 3 or higher. This new filter is also computational inexpensive.

8383B-23, Session 2

Biocular vehicle display optical designs

K. M. MacIntyre, SCHOTT North America, Inc. (United States)

SCHOTT North America specializes in designing and fabricating coherent fiber optics imaging systems for aerospace/defense, medical, and transportation applications. These modules are used to relay, invert, and magnify/de-magnify images in optical systems.

With the recent conversion from analog CRT based displays to lighter, more compact AMOLED digital image sources, display optical designs have evolved to take advantage of the higher resolution AMOLED image sources.

The coherent taper fiber modules are used extensively:

1. To convert plano focal planes to spherical focal planes in order to eliminate Petzval field curvature. This elimination enables faster lens speed and/or larger field of view of eye pieces, display optics.

2. To provide pre-magnification to lighten the work load of the optics to further increase the numerical aperture and/or field of view of the optics.

3. To improve light flux collection efficiency and optical performance by guiding imaging light bundles toward the lens aperture stop. The guidance reduces the overall optical packaging volume.

This paper will review and compare the performance of biocular vehicle display designs with and without taper fiber module.

The biocular vehicle displays provide operational information to commanders, drivers, and gunners of tracked or wheeled vehicles. They can also provide operational information to operators of UAV.

8383B-08, Session 3

Recent advances in AMOLED display technologies for application to aerospace and military systems

K. R. Sarma, Honeywell Technology (United States)

Compared to the current AM LCD (active matrix liquid crystal display), AM OLED (active matrix organic light emitting diode) display offers the advantages of superior image quality, and a potential for superior SWAP (size, weight and power) characteristics, higher level of ruggedness, and lower cost. AM OLEDs have been under active development for more than 10 years. Recently, there have been significant advances in various components of the AM OLED technology including R,G,B OLED device efficiency and lifetime, pixel patterning technologies, and TFT backplane technologies enabling high volume manufacturing of OLED displays for a variety of consumer applications such as premium displays for smart phones. In this paper we will discuss these recent advances in detail, and assess the readiness of the current state-of-the-art OLED display technology for application to aerospace and military systems.

8383B-10, Session 3

Ultra-high resolution and high-brightness AMOLED

I. Wacyk, A. Ghosh, O. Prache, eMagin Corp. (United States); R. Draper, D. A. Fellowes, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

As part of its continuing effort to improve both the resolution and optical performance of AMOLED microdisplays, eMagin has recently developed an SXGA (1280x3x1024) microdisplay under an NVESD contract that combines the world's smallest OLED pixel pitch with an ultra-high brightness green OLED emitter. This development is aimed at next-generation HMD systems with "see-through" and daylight imaging requirements. The OLED pixel array is built on a 0.18-micron CMOS backplane and contains over 4 million individually addressable pixels with a pixel pitch of 2.7 x 8.1 microns, resulting in an active area of 0.53 inches diagonal. Using both spatial and temporal enhancement, the display can provide over 10-bits of gray-level control for high dynamic range applications. The new pixel design also enables the future implementation of a full-color QSXGA (2560 x RGB x 2048) microdisplay in an active area of only 1.05 inch diagonal. A low-power serialized low-voltage-differential-signaling (LVDS) interface is integrated into the display for use as a remote video link for tethered systems. The new SXGA backplane has been combined with the high-brightness green OLED device developed by eMagin under an NVESD contract. This OLED device has produced an output brightness of more than 3000fL with all pixels on; lifetime measurements are currently underway and will presented at the meeting. This paper will describe the operational features and first optical and electrical test results of the new SXGA demonstrator microdisplay.

8383B-11, Session 3

Bio-kinetic energy harvesting using electroactive polymers

J. Slade, Infoscitex Corp. (United States)

In hybrid vehicles, electric motors are used on each wheel to not only

propel the car but also to decelerate the car by acting as generators. In the case of the human body, muscles spend about half of their time acting as a brake, absorbing energy, or doing what is known as negative work. Using dielectric elastomers it is possible to use the "braking" phases of walking to generate power without restricting or fatiguing the Warfighter.

Infoscitex and SRI have developed and demonstrated methods for using electroactive polymers (EAPs) to tap into the negative work generated at the knee during the deceleration phase of the human gait cycle and convert it into electrical power that can be used to support wearable information systems, including display and communication technologies. The specific class of EAP that has been selected for these applications is termed dielectric elastomers. Because dielectric elastomers dissipate very little mechanical energy into heat, greater amounts of energy can be converted into electricity than by any other method.

The long term vision of this concept is to have EAP energy harvesting cells located in components of the Warfighter ensemble, such as the boot uppers, knee pads and eventually even the clothing itself. By properly locating EAPs at these sites it will be possible to not only harvest power from the negative work phase but to actually reduce the amount of work done by the Warfighter's muscles, thereby reducing fatigue and minimizing the forces transmitted to the joints.

8383B-12, Session 4

Coherent visualization of spatial data adapted to roles, tasks, and hardware

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Modern crisis management requires that users with different roles and computer environments have to deal with a high volume of various data from different sources. For this purpose, the Fraunhofer IOSB has developed a geographic information system (GIS) which supports the user depending on available data and the task he has to solve.

The system provides the merging and visualization of spatial data from various civilian and military sources. It supports the most common spatial data standards (OGC, STANAG) as well as some proprietary interfaces. Regardless if these are file-based or database-based.

To set the visualization rules generic Styled Layer Descriptors (SLDs) are used, which is an Open Geospatial Consortium (OGC) standard. SLD allow to specify which data are shown, when and how. The defined SLD consider the display resolution, as well as the user's roles and task requirements.

Thus it is possible to use different display and the visualization adapts also to the individual resolution of the display. Too high or low information density is avoided.

Also our system enables that user with different roles work together simultaneously using the same data base. Every user is provided with the appropriate and coherent spatial data depending on his actual task.

These so refined spatial data are served via the OGC services Web Map Service - WMS (server-side rendered raster maps), or the Web Map Tile Service - WMTS (pre-rendered and cached raster maps).

8383B-13, Session 4

A low-bandwidth implementation for wireless video surveillance

T. E. Brown II, J. Pierce, L-3 Display Systems (United States)

Public safety entities are experiencing an ever increasing demand for video surveillance to improve their ability to secure remote locations, monitor areas of concern that change over time, or provide added support for special events. The cost with adding the needed infrastructure is often prohibitive to support a short term need. Previous efforts to transmit video wirelessly have resulted in low frame rates and high bandwidth requirements that offer little useful real time data and frustrate end users due to high latency and poor video quality. This paper provides a simple, cost effective approach to provide portable video streaming capabilities to the public safety community using commercially available technology.

8383B-14, Session 4

Video analytics for improved surveillance

T. E. Brown II, J. Pierce, L-3 Display Systems (United States)

The proliferation of video data has resulted in an information deluge that is impossible for personnel to vigilantly monitor. The added surveillance creates the false sense of security given the perception that the sensors are constantly monitored by personnel that are not only properly trained but fully alert. This paper will present the features of a system that can autonomously monitor scenes and provide alarms for intrusions, left behind objects in a crowded scene, missing objects, smoke and fire, license plate recognition or simply counting people/objects.

8383B-15, Session 4

Future display considerations for security applications

J. E. Fulton, Jr., G. M. Nicholson, G. J. Petty, E. J. Seals, Naval Surface Warfare Ctr. Crane Div. (United States)

Advancing the state of the art in security applications today means reducing the human resources necessary to perform the task. Agencies have the basic need to provide for security, which is personnel intensive, but the cost of providing the minimum acceptable coverage is challenging. This paper discusses how haptic devices, automated cuing technology, detethering displays devices, and effective display usage can directly affect how many billets are necessary for security applications.

8383B-16, Session 4

Free-space optical applications with head-mounted displays

G. Hays, L. Volfson, Torrey Pines Logic, Inc. (United States)

As the data, intelligence, and information become a larger part of the battlefield, soldiers are relying more on helmet mounted displays (HMD) in order to provide a method to not only keep critical data within easy reach, but to also stay as covert as possible by eliminating the screen glare from a laptop. However, there is a large drawback to the systems that needs significant remediation. Current HMD and headsets require cables to be routed from the soldier's body worn or vehicle mounted systems to the devices on their helmets and heads.

The ideal solution would be to make the system wireless. The problem is radio frequency (RF) based systems are inherently not optimum for these types of connections for many reasons. Torrey Pines Logic (TPL) is one of the leaders in the area of non-RF wireless HMD and headset technology. TPL is currently under contract with the Air Force Research Lab (AFRL) to develop a solution to remove the tethered cables from Battlefield Airmen equipment using our light emitting diode (LED) LightSpeed free-space communication system. This has given them unprecedented experience with the problem and many of the shortcomings of current solution attempts. Many non-RF systems have already been tested by AFRL, such as magnetic and ultrasonic wireless systems. Though these systems can handle audio, they do not scale well for video even at close distances. They are further unusable at distances over a few meters. This has led AFRL to work on an optically based solution.

8383B-17, Session 5

Three-dimensional system integration for HUD placement on a new tactical airlift platform: design eye point vs. HUD eye box with accommodation and perceptual implications

S. D. Harbour, U.S. Air Force Aeronautical Systems Ctr. (United States)

The retrofitting of a cockpit with a Head-Up-Display (HUD) raises potential accommodation and perceptual issues for pilots that must be addressed. For maximum optical efficiency the goal is to be able to place every pilot's eye into the HUD Eye Motion Box (EMB) given a seat adjustment range. Initially, the Eye Reference Point (ERP) of the EMB should theoretically be located on the aircraft's original cockpit Design Eye Point (DEP), but human postures vary, and HUD systems may not be optimally placed. In reality there is a distribution of pilot eyes around the DEP (dominate eye dependent), therefore this must be accounted for in order to obtain appropriate visibility of all of the symbology based on photonic characteristics of the HUD. Pilot size and postural variation need to be taken into consideration when positioning the HUD system to ensure proper vision of all HUD symbology in addition to meeting the basic physical accommodation requirements of the cockpit. The innovative process and data collection methods for maximizing accommodation and pilot perception on a new "tactical airlift" platform are discussed as well as the related neurocognitive factors and the effects of information display design on cognitive phenomena.

8383B-19, Session 5

What is 3D good for? A review of human performance on stereoscopic 3D displays

J. P. McIntire, P. R. Havig, E. E. Geiselman, Air Force Research Lab. (United States)

This work reviews the Human Factors-related literature on the task performance implications of stereoscopic 3D displays, in order to point out the specific performance benefits (or lack thereof) one might reasonably expect to observe when utilizing these displays. What exactly is 3D good for? Relative to traditional 2D displays, stereoscopic displays have been shown to enhance performance on a variety of depth-related tasks. These tasks include judging absolute and relative distances, finding and identifying objects (by breaking camouflage and eliciting perceptual "pop-out"), performing spatial manipulations of objects (object positioning, orienting, and tracking), and navigating. More cognitively, stereoscopic displays can improve the spatial understanding of 3D scenes or objects, improve memory/recall of scenes or objects, and improve learning of spatial relationships and environments. For tasks that are relatively simple, that do not strictly require depth information for good performance, where other strong cues to depth can be utilized, or for depth tasks that lie outside the effective viewing volume of the display, the purported performance benefits of stereoscopy may be small or altogether absent. Stereoscopic 3D displays come with a host of unique Human Factors problems including the simulator-sickness-type symptoms of eyestrain, headache, fatigue, disorientation, nausea, and malaise, which appear to effect large numbers of viewers (perhaps as many as 25% of the general population). Thus, 3D technology should be wielded delicately and applied carefully; and perhaps used only as is necessary to ensure good performance.

8383B-20, Session 5

Air force pilot's wrist computing system

M. J. Moore, N. Beke, M. Torres, Impact Technologies (United States)

Advances in electronic packaging, low power computing, and wireless technology enable the development of an aesthetic and wearable wrist computing platform suitable for warfighters and patient health monitoring. This wearable computing platform allows communication and navigation as well as wireless monitoring and storage of environmental, biometric and equipment data. The platform incorporates Freescale's i.MX family of low power processors running Android. System-in-Package and embedded antenna technology facilitates a modular wireless architecture. This approach incorporates multiple wireless protocols such as Zigbee 802.15.4, Bluetooth, and WiFi, as well as solutions for broad band long range communication.

Previous attempts for a computing platform in this size were relegated to custom multi chip module (MCM) technology at a significantly higher cost point. This platform demonstrates circuit miniaturization using COTS available components with advanced packaging. Utilizing Endicott's CoreEZ advanced PCB technology and embedded passive components, standard chip scale packages such as the processor and memory can be incorporated into a wearable small form factor. The watch band which is traditionally non functional is utilized as a sensor platform with novel flexible circuits and woven electronics. Functionality is maximized while still providing an aesthetic and useable profile.

Display and IO functionality for the wrist computing platform are achieved using an OLED display with touch controls. OLED technology is selected due to its low profile and low power consumption. The wrist computing platform offers maximum functionality with novel technology with the familiarity of the Android OS. Thus, the user experience is similar to a smart phone implementation.

8383B-21, Session 5

Considerations for optimizing power and data cables for warfighter's body worn technologies

C. S. Washington, A. J. Hull, Air Force Research Lab. (United States)

Today's warfighters deploy into asymmetric and austere environments performing complex duties utilizing wearable technologies. Accordingly, these technologies are required to be integrated into an ergonomic mission effective ensemble while providing ease of use. Interconnecting the technologies, wearable cables provide mission essential interoperability between the various peripheral devices worn by the operator. Snag hazards, excessive weight, thermal radiation, water resistance and cable entanglement are just a few of the ergonomic factors that have to be addressed to enhance operator effectiveness. Cable management solutions have to be robust enough to accommodate individual preferences on types of cables and technology placement on the human chassis.

The objective of this effort is to evaluate the placement of key body worn equipment to investigate optimal wearable cable integration for operators. Emerging cable technologies' performance such as current capacity, shielding, water resistance will be assessed to identify cabling options suitable for high tempo missions conducted by dismounted operators.

8383B-22, Session 5

ARINC 818 Express for high-speed avionics video and power over coax

T. Keller, J. A. Alexander, Great River Technology, Inc. (United States)

CoaXpress is a new standard for high speed video over coax cabling developed for the machine vision industry. CoaXpress includes both a physical layer and a video protocol. The physical layer has desirable features for aerospace and defense applications: it allows 3Gbps (up to 6Gbps) communication, includes 100Mbps return path allowing for bidirectional communication, and provides up to 13W of power, all over a single coax connection. ARINC 818, titled “Avionics Digital Video Bus” is a protocol standard developed specifically for high speed, mission critical aerospace video systems. ARINC 818 is being widely adopted for new military and commercial display and sensor applications. The ARINC 818 protocol combined with the CoaXpress physical layer provide desirable characteristics for many aerospace systems.

This paper presents the results of a technology demonstration program to marry the physical layer from CoaXpress with the ARINC 818 protocol. ARINC 818 is a protocol, not a physical layer. Typically, ARINC 818 is implemented over fiber or copper for speeds of 1 to 2Gbps, but beyond 2Gbps, it has been implemented exclusively over fiber optic links. In many rugged applications, a copper interface is still desired, by implementing ARINC 818 over the CoaXpress physical layer, it provides a path to 3 and 6 Gbps copper interfaces for ARINC 818.

Results of the successful technology demonstration dubbed ARINC 818 Express are presented showing 3Gbps communication while powering a remote module over a single coax cable. The paper concludes with suggested next steps for bring this technology to production readiness.

8383B-24, Session 5

Cockpit considerations for helmet-mounted SWIR imaging systems

G. J. Grabski, J. Green, M. A. Jacobson, T. R. Robinson, Esterline Control Systems (United States)

In the past two decades, night vision goggle (NVG) technology has made significant advances. The advances in GaAs materials technologies have raised the bar for alternative technologies. Resolution, gain, and sensitivity have all improved and digital NVG devices are on horizon. The image quality through NVGs is outstanding over a wide range of conditions.

Insertion of NVGs in aircraft during the late 70’s and early 80’s resulted in many “lesson learned” situations concerning instrument compatibility with NVGs. These “lessons learned” ultimately resulted in specifications such as MIL-L-85762A and MIL-STD 3009. These specifications are now used throughout industry to produce NVG-compatible illuminated instruments and displays for both military and civilian applications.

The advances night vision goggles have not precluded alternative night vision technologies such as one based on the InGaAs focal plane array. Although this system has been used for external cockpit sensors, development is under way for helmet-mounted applications. The InGaAs imaging systems offers advantages over existing NVGS. Two key advantages are; 1) the new imaging system can output a digital image, and 2) the new system is sensitive to energy in the short-wave infrared (SWIR) spectrum.

This paper describes SWIR testing of cockpit illuminated components and materials that has revealed certain types legacy illuminated products can impact sensitivity of the SWIR imaging system similar to that seen with large area displays and night vision goggles. Additional impacts to the SWIR imaging system sensitivity may result of the increase absorption in the SWIR region of the cockpit transparencies and increased SWIR reflectance because of thin film coatings. The Air Force Research Laboratory (AFRL) is sponsors this project.

8383B-01, Poster Session

Military display performance parameters

D. D. Desjardins, F. M. Meyer, Air Force Research Lab. (United States)

The military display market is analyzed in terms of four of its segments: avionics, vetronics, dismounted soldier, and command and control. Requirements are summarized for a number of technology-driving parameters, to include luminance, night vision imaging system compatibility, gray levels, resolution, dimming range, viewing angle, video capability, altitude, temperature, shock and vibration, etc., for direct-view and virtual-view displays in cockpits and crew stations. Analysis and comparison of military display performance parameters shall be made between platform applications within segments and between applications across segments. Technical specifications shall be discussed for selected programs.

8383B-18, Poster Session

3D laptop for defense applications

R. Edmondson, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

Polaris Sensor Technologies has developed numerous 3D display systems using a US Army patented approach. These displays have been developed as prototypes for handheld controllers for robotic systems and closed hatch driving, and as part of a TALON robot upgrade for 3D vision, providing depth perception for the operator for improved manipulation and hazard avoidance. In this paper we discuss the prototype rugged 3D laptop computer and its applications to defense missions. The prototype laptop combines full temporal and spatial resolution 3D display with the rugged Amrel laptop computer. The display is viewed through protective passive polarized eyewear, and allows combined 2D and 3D content. Uses include robot tele-operation with live 3D video or synthetically rendered scenery, mission planning and rehearsal, enhanced 3D data interpretation, and simulation.

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8384-01, Session 1

Holographic 3D display using MEMS spatial light modulator

Y. Takaki, Tokyo Univ. of Agriculture and Technology (Japan)

A new holographic 3D display technique that increases both the screen size and the viewing zone angle is presented. A MEMS spatial light modulator (SLM) is used for high-speed image generation. The image generated by the SLM is de-magnified horizontally and magnified vertically using an anamorphic imaging system. The vertically enlarged images are aligned horizontally by a galvano scanner. The screen size of 4.3 inches and a horizontal viewing zone angle of 15° were obtained at a frame rate of 60 fps. The modulation of a laser illuminating the SLM improves the grayscale representation of 3D images.

8384-02, Session 1

Face and eye tracking for subhologram-based digital holographic display system

J. Kim, H. K. Lee, J. Cha, J. Nam, Electronics and Telecommunications Research Institute (Korea, Republic of)

Digital holographic 3DTV display requires its size large enough for experiencing full 3-dimensional images without wearing any special glasses: e.g. bigger than 50 inches diagonal, which is typical flat-panel HDTV now. However, within a foreseeable period of time, it seems that such a big holographic display would not be realizable with conventional way of wide viewing angle implementation of holographic display. Thus sub-hologram based holographic display method is one of the most practical approaches for realizing big size holographic display. However, sub-hologram based holographic display method needs highly accurate and robust real-time face and eye tracking function to be implemented and synchronously working with sub-hologram generation. Accurate and fast operation of the eye tracking enables precise steering of backlight and generation of corresponding sub-hologram for each video frame.

We theoretically estimated several parameters required for the eye tracking system based on a typical human behavior of TV watching, and developed an eye tracking camera system and algorithm which can be used for many practical applications like a new user interface for TV control. We experiment the accuracy, speed and robustness of tracking under different disturbing conditions, and show that requirements for sub-hologram based display system could be fully met with our implementation. This eye tracking system will eventually be integrated into the holographic display.

8384-03, Session 1

Spatial light modulator-based phase-shifting Gabor holography

V. Micó, J. García, Univ. de València (Spain); Z. Zalevsky, Bar-Ilan Univ. (Israel); B. Javidi, Univ. of Connecticut (United States)

We present a modified Gabor-like setup able to recover the complex amplitude distribution of the complex wavefront diffracted by a sample from a set of in-line recorded holograms. The proposed configuration is based on a modified Gabor-like setup where a condenser lens and a spatial light modulator (SLM) are inserted in a classical Gabor configuration. The phase-shift is introduced by the SLM that modulates the central spot (DC term) of the sample's spectrum which is provided by the condenser lens in an intermediate plane before the electronic recording device. As consequence, the proposed imaging system recovers the complex amplitude distribution of the diffracted sample wavefront without an additional reference beam. Experimental results validate the proposed method and produce superior results to the Gabor method in both cases, that is, for those cases when the Gabor approach (weak diffractive samples) can be assumed or not.

8384-04, Session 1

3D visual systems using integral photography camera, camera array, and electronic holography display

K. Yamamoto, Y. Ichihashi, T. Senoh, R. Oi, T. Kurita, National Institute of Information and Communications Technology (Japan)

This paper introduces two 3D visual systems using ray-based image sensors and electronic holography display toward ultra-realistic communication. The first system uses integral photography for the capture of ray information at slightly separated locations. The second system uses camera array that includes 300 cameras to capture ray information at more sparse locations than integral photography. Both systems use electronic holography as an ideal 3D display. Since spatial light modulators are currently inadequate specifications for electronic holography, the setup to remove disturbing light is necessary, which we implemented in both systems.

For the first system, we designed and manufactured a 300-camera array system. Each camera in the system has 1600x1200 pixels, and the cameras are located on a circle at intervals of 1.2 degrees, which are intervals of approximately 32 mm. All of the cameras have been placed at the desired locations and are oriented to face the subject as best as possible. However, before using the captured images, we have to modify them due to the deviations caused by the cameras not being able to physically face the subject properly or by scattering of intrinsic parameters. In this paper, we will briefly mention how to simply detect the deviations and modify the captured images.

8384-05, Session 1

Is it worth using an array of cameras to capture the spatio-angular information of a 3D scene or is it enough with just two?

H. Navarro, M. Martinez-Corral, G. Saavedra-Tortosa, Univ. de València (Spain); B. Javidi, Univ. of Connecticut (United States)

An analisis and comparison of the lateral and the depth resolution in the reconstruction of 3D scenes from images obtained either with a classical two view stereoscopic camera or with an Integral Imaging (InI) pickup setup is presented.

Since the two above systems belong to the general class of multiview imaging systems, the best analytical tool for the calculation of lateral and depth resolution is the ray-space formalism, and the classical tools of Fourier information processing.

We demonstrate that InI is the optimum system to sampling the spatio-angular information contained in a 3D scene.

8384-06, Session 1

Electro-holography display using computer-generated hologram of 3D objects based on projection spectra

S. Huang, D. Wang, T. Wang, Shanghai Univ. (China)

Holography is able to provide the most authentic three-dimensional (3D) illusion to the human eye without the need for special viewing devices. Computer generated holography has become an important technique in 3D imaging, it can yield ideal 3D visual effects even for virtual 3D objects. A new method of synthesizing computer-generated hologram (CGH) of 3D objects from their projection images is proposed. Numerical reconstruction of the hologram has been achieved. Electro-holography display of the hologram can be implemented.

A series of projection images of 3D objects are recorded with one-dimensional azimuth scanning. According to the principles of paraboloid of revolution in 3D Fourier space and 3D central slice theorem, spectra information of 3D objects can be gathered from their projection images. Because there is quantization error of horizontal and vertical directions, in order to make full use of projection spectra, the spectrum information of each projection image is extracted in double circle even four circles form. Spectrum information obtained from all projection images is used to fill the u-v plane. Then the wavefront distribution of 3D object at the Fourier plane is achieved. The complex matrix can be encoded efficiently into CGH of 3D objects based on computer-generated holography using a conjugate-symmetric extension. Experimental results for numerical reconstruction of the CGH at different distance validate the proposed methods and show its good performance.

Electro-holographic reconstruction can be realized by using an electronic addressing reflective liquid-crystal display (LCD) spatial light modulator. The CGH from the computer is loaded onto the LCD. By illuminating a reference light from a laser source to the LCD, the amplitude and phase information included in the CGH will be restored. The 3D objects can be reconstructed in the distance due to the diffraction of the light modulated by the LCD.

8384-07, Session 2

An autofocusing algorithm for digital holograms

P. Ferraro, P. Memmolo, C. Distante, M. Paturzo, A. Finizio, Istituto Nazionale di Ottica (Italy); B. Javidi, Univ. of Connecticut (United States)

We propose an algorithm for the automatic estimation of the in-focus image and the recovery of the correct reconstruction distance for digital holograms. We tested the proposed approach applying it to stretched digital holograms. In fact, by stretching an hologram with a variable elongation parameter, it is possible to change the in-focus distance of the reconstructed image. In this way, the reliability of proposed algorithm can be verified at different distances dispensing with the recording of different holograms. Experimental results are shown with the aim to demonstrate the usefulness of the proposed method and a comparative analysis has been performed with respect to other algorithms developed for digital holography.

8384-08, Session 2

Recognition and classification of red blood cells using three-dimensional digital holographic imaging and data clustering with discriminant analysis

R. Liu, D. K. Dey, Univ. of Connecticut (United States); D. Boss, P. Marquet, Ecole Polytechnique Fédérale de Lausanne (Switzerland); B. Javidi, Univ. of Connecticut (United States)

Automatic recognition and classification of different states of biological cells is a challenging and important problem for diagnostic as well as therapeutic application. In particular, as far as red blood cells (RBCs) are concerned classification based on their duration of storage are highly relevant. Indeed, the duration of storage before transfusion may alter RBC function and, therefore, influence the incidence of complications in patients. In this paper, we propose the use of statistical clustering algorithms on 3D profile of RBCs obtained through a Digital Holographic Microscopy (DHM) system. It is shown that two classes of RBCs stored for 14 and 38 days respectively, can be effectively classified. Two dimensional intensity images of the two specimens are virtually the same, however, DHM allows for measurement of RBCs' bi-concave profile, resulting in a discriminative dataset. Two statistical clustering algorithms are compared: 1) The model-based clustering approach classifies the pixels of a RBC and recognizes the RBC as either new or old based on the classification of its pixels; 2) K-means algorithm is applied to the 4-dimensional feature vector (extracted from the bi-concave profile for each RBC). The performance of classification is quantified and the results suggest that old and new RBCs can be classified with accuracy of 80% and 100% respectively. The proposed methods may provide real-time, non-invasive, low cost and highly parallel method for recognition and classification of different states of RBCs.

8384-09, Session 2

3D microscopic imaging at 193nm with single beam Fresnel intensity sampling and iterative phase retrieval

A. Anand, Maharaja Sayajirao Univ. of Baroda (India); A. Faridian, Univ. Stuttgart (Germany); V. Chhaniwal, Parul Trust (India); G. Pedrini, W. Osten, Univ. Stuttgart (Germany); B. Javidi, Univ. of Connecticut (United States)

3D imaging requires the retrieval of both amplitude and phase of the wavefront interacting with the object. Quantitative phase contrast imaging technique like digital holography uses the interference of object and a known reference wavefront for whole field reconstructions. And for higher lateral resolution, uses of shorter wavelengths become necessary. For short wavelength sources, due to short coherence lengths, it becomes very difficult to implement a two-beam interferometric setup. We have developed a technique for reconstructing the amplitude and phase of object wavefront from the volume diffraction field by sampling it at several axial positions and implementing the scalar diffraction integral iteratively. This technique is extended to 3D microscopic imaging at 193 nanometers.

8384-10, Session 3

Combining in-depth viewing and color visual cryptography for securing color image display

J. Machizaud, T. Fournel, Lab. Hubert Curien (France)

In this work, we propose to improve the secure information display introduced by Yamamoto et al. [1] in order to display full color images. Yamamoto's technique makes use of black and transparent mask as decoding shadow image of a visual cryptography scheme sharing 3 bits multi-color messages. By combining in-depth setup together with a color visual cryptography (VC) scheme which does not use any mask, we can securely display color images. A satisfying VC scheme is provided by Hou et al. [2] by coding the color of the message with a white pixel and three colored pixels (with primary inks) which can be printed on a transparency film. When printed, colors act as filters [3] and allow a wider color gamut for the message which is not limited to saturated color as in [1] because of the black and transparent mask as shadow image. In our implementation of the two-out-of-two visual cryptography scheme which shares a secret message into two color shadow images, the first one is projected on a glass diffuser and the second one is printed on a transparency. The registration method introduced in [4] is used in order to overcome the difficulty of shadow image alignment. As the two shadow images are superposed with an air layer, the message disappears when the angular position is not the accurate one. Examples with binary colored message and with color images are provided to show the improvements. By moving the detector (or the eyes) angularly around the right position, perspective effects can be perceived.

8384-11, Session 3

Unknown sensor position estimation in axially distributed sensing 3D imaging

X. Xiao, B. Javidi, Univ. of Connecticut (United States)

An axially distributed sensing system is a 3D sensing and imaging where the sensors are distributed along the optical axis. In this system, a priori knowledge of exact sensor positions was required for 3D volume image reconstruction. In this paper, we overview unknown sensor position estimation method and present an axially distributed sensing with unknown sensor positions. Experiments illustrate the feasibility of the proposed system and show this new system may improve the visual quality of 3D reconstructed images.

8384-12, Session 3

Atmospherical wavefront phases using the plenoptic sensor (real data)

J. M. Rodríguez Ramos, Univ. de La Laguna (Spain); L. F. Rodríguez-Ramos, I. Montilla, Instituto de Astrofísica de Canarias (Spain); M. López-Marrero, J. J. Fernández-Valdivia, J. P. Lüke, J. G. Marichal-Hernández, F. L. Rosa González, Univ. de La Laguna (Spain); R. López López, B. Femenía Castellá, Instituto de Astrofísica de Canarias (Spain)

Plenoptic cameras have been developed the last years as a passive method for 3d scanning, allowing focal stack capture from a single shot. But data recorded by this kind of sensors can also be used to extract the wavefront phases associated to the atmospheric turbulence in an astronomical observation.

The terrestrial atmosphere degrades the telescope images due to the diffraction index changes associated to the turbulence. These changes require a high speed processing hardware, the use of the GPUs and the FPGAs is then justified. Na artificial Laser Guide Stars (Na-LGS, 90km high) must be used to obtain the reference wavefront phase and the Optical Transfer Function of the system, but they are affected by defocus because of the finite distance to the telescope.

Using the telescope as a plenoptic camera allows us to correct the defocus and to recover the wavefront phase tomographically, taking advantage of the two principal characteristics of the plenoptic sensors at the same time: 3D scanning and wavefront sensing. Then, the plenoptic sensors can be studied and used as an alternative wavefront sensor for Adaptive Optics, particularly relevant when Extremely Large Telescopes projects are being undertaken.

In this paper, we will present the first observational wavefront phases extracted from real astronomical observations, using punctual and extended objects.

8384-13, Session 3

Multiple objects tracking in unknown background using Bayesian estimation in 3D space

Y. Zhao, X. Xiao, M. Cho, B. Javidi, Univ. of Connecticut (United States)

In this paper, we present tracking of multiple occluded 3D objects using a region tracking method based on statistical Bayesian formulation, and 3D integral imaging used for passive sensing and computational 3D scene reconstruction. It is assumed that the background is stationary for each frame. We also assume that the reconstructed pixel intensities of both background and multiple objects are independent identically distributed (i.i.d.). In 3D integral imaging reconstruction of the scene, the optical rays generated by elemental images are superimposed. Thus, the background region of the reconstructed images tends to be Gaussian distributed by applying the central limit theorem. The statistical behavior of various objects may be different, and a Gamma distribution is chosen as a robust statistical distribution to capture the object pixel distributions. Therefore, we assume that the reconstructed pixel intensities of both background and multiple objects follow Gaussian and Gamma distributions based on their grayscale images, respectively. Within the Bayesian framework, posterior probabilities of background and objects are calculated by assuming appropriate prior distributions for estimated parameters. At each incoming frame, the 3D scene is reconstructed. Then, the objects are located in 2D slices of the 3D reconstructed scene by maximizing the geodesic distance between the log-posteriors of the reconstructed background and objects to be tracked. Then, each object is tracked individually in 3D space by maximizing the above distance across all the 2D reconstructed planes. The algorithm can work with objects with unknown position, rotation, scale and illumination. We have shown that statistical Bayesian formulation used with 3D integral imaging provides a promising technique for tracking objects in the 3D space.

8384-14, Session 3

A 3D x-ray security checkpoint screening device with image rotation

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The 2-D X-ray security checkpoint scanner first developed in the 1970's is the most common system in use to protect our nation's critical infrastructure including airports, rail terminals, public buildings and schools. Although modifications and improvements have been made through the years, a primary problem with the 2-D X-ray security checkpoint scanner is that the radiographic image is a 2-D superposition of all objects within the item being screened. This superposition of images makes deliberate concealment of contraband easier and increases the workload and stress on the human inspector trying to interpret these images. The 3-D luggage screening device developed by NASA was patented shortly after 911 and was inspired by the 3-D imagery that NASA used for remote operation of robotic devices on Mars. Unlike 3-D X-ray images generated through Computed Tomography algorithms this device relies on the stereo-perceptive abilities of the human-in-the-loop and, as a result, can operate at throughput rates comparable to a 2-D luggage scanner. In a second patent now pending the NASA device was modified to allow the display of 3-D X-ray images which may be rotated through a limited angle to further assist in the identification of contraband. This paper describes the 3-D X-ray security checkpoint scanner in comparison to other screening technologies. An overview of the current metrics used to evaluate these screening systems and the planned development and testing activities for the 3-D X-ray scanner will also be presented.

8384-15, Session 3

High-accuracy, real-time pedestrian detection system using 2D and 3D features

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We present a real time stereo-vision pedestrian detector implementation with a very high accuracy, the 2D component of which attains 99% recall with less than 10-4 false positives per window on the INRIA persons dataset. We utilize a sequence of classifiers which use different features, beginning with simple constraints, testing with haar-like features and a haar-like feature implementation adapted to disparity images, and performing a final verification with Histogram-of-Oriented Gradient (HOG) features. We present a 2D haar-like feature implementation that utilizes 2x2 kernel filters at multiple scales rather than integral images, and combines a quickly trained preliminary adaBoost classifier with a more accurate SVM classifier. We also show how these haar-like features may be computed from a partially incomplete stereo disparity image

in order to make use of 3-dimensional data. Finally, we discuss how these features, along with the HOG features, are computed rapidly and how the classifiers are combined in such a way as to enable real-time implementation with higher detection rates and lower false positive rates than typical systems. Our overall detector is a practical combination of speed and strength, operating on 544x409 image (10,425 windows) at a frame rate of 10-20fps, depending on scene complexity. The detector's overall false positive rate is less than 10-6 , corresponding to about one false positive every 10-60s when testing on our non-training data. Additionally, the detector has shown usefulness for detecting other object types, and has been implemented for traffic cones, telephone poles, and vehicles.

8384-16, Session 4

Ray-space acquisition system for 3DTV

T. Fujii, Nagoya Univ. (Japan)

3D TV requires multiple view images and it is very important to adjust parameters used for capturing and display of multiview images, which includes size of view images, focal length, and camera/viewpoint interval. However, the parameters usually vary from systems to systems and that causes a problem regarding interconnectivity between capturing and display devices. The Ray-Space method provides one of the solutions to such problems raised in 3D TV data capturing, transmission, storing, and display. In this paper, we first review the Ray-Space method and describe its relationship with 3D TV. Then, we introduce 3 types of Ray-Space acquisition systems: 100-camera system, space/time-division system, and portable multi-camera system. We also describe test data set provided for MPEG (Moving Picture Experts Group) Multiview Video Coding and 3D Video activities.

8384-17, Session 4

Interactive 3D crosstalk simulator for autostereoscopic display design

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Generally human factors are used to make systems safe, efficient, and comfortable for humans on the basis of knowledge about humans' abilities and limits. To minimize undesirable biomedical effects viewers' attributes, visual contents, viewing environments, display, and device factors are investigated. Studies show that crosstalk causes distortions, reduces image quality and visual comfort, and increases perceived workload. Moreover, there is evidence that crosstalk effects depth perception from disparity. Also, crosstalk causes serious fatigue, headache, eyestrain and etc. Thus, 3D display system and 3D contents have to be designed to minimize crosstalk.

Interactive 3D crosstalk simulator for autostereoscopic display calculates light distribution and crosstalk from given parameters. the 3D simulator makes use of optimized parameters such as the number of barrier, the number of aperture, light distribution, crosstalk and observation area along the z axis by some parameters such as the size of display, resolution, viewing distance from the parallax barrier, view points, inter distance between the display plane and the parallax barrier, width of a unit pixel, width of an electrode, binocular distance and etc to find comfort viewing zone.

8384-18, Session 4

Virtual 3D interactive system with embedded multiwavelength optical sensor array and sequential devices

G. Wang, National Chiao Tung Univ. (Taiwan) and Industrial Technology Research Institute (Taiwan); Y. Huang, National Chiao Tung Univ. (Taiwan); K. Hu, Industrial Technology Research Institute (Taiwan)

We proposed a virtual 3D-touch system, which can detect the 5-axis (x, y, z, ,) information to really interact with and touch on the 3D images. This system has optical sensor array embedded on the backplane of TFT panel, thus can has very slim structure. We had developed both lighting and reflecting mode, which can be worked on different environment, for the 3D interaction. A 4-inch mobile 3D-LCD with this embedded 3D interactive system was successfully been demonstrated already.

8384-39, Poster Session

Auto-converging stereo cameras for 3D robotic tele-operation

R. Edmondson, T. Aycock, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

Polaris Sensor Technologies has developed a Stereovision Upgrade Kit for TALON robot to provide enhanced depth perception to the operator. This kit previously required the TALON Operator Control Unit to be equipped with the optional touchscreen interface to allow for operator control of the camera convergence angle adjustment. This adjustment allowed for optimal camera convergence independent of the distance from the camera to the object being viewed. Polaris has recently improved the performance of the stereo camera by implementing an Automatic Convergence algorithm in a field programmable gate array in the camera assembly. This algorithm uses scene content to automatically adjust the camera convergence angle, freeing the operator to focus on the task rather than adjustment of the vision system. The autoconvergence capability has been demonstrated on both visible zoom cameras and longwave infrared microbolometer stereo pairs.

8384-40, Poster Session

Performance evaluation of 3D photon counting integral imaging for object recognition

I. Moon, Chosun Univ. (Korea, Republic of)

In this paper, the performance evaluation of a 3D photon counting integral imaging (PCII) system for objects recognition is overviewed. We quantitatively compare object recognition performance of PCII system with that of object recognition using 2D gray scale images and conventional 3D integral imaging. To evaluate photon counting object recognition performance, normalized correlation peak values between three-dimensionally reconstructed reference object and unknown input objects are computed for the varied total number of photons or the fixed one in the reconstructed sectional image changing the total number of image channels in the PCII system.

8384-41, Poster Session

Space bandwidth product analysis of digital holography applied to video hologram recording and reconstruction

A. Phan, J. Park, N. Kim, Chungbuk National Univ. (Korea, Republic of)

In this paper, we present an analysis on space bandwidth product of digital hologram. The condition for clear reconstruction of in-axis and off-axis digital hologram cases is derived. The presented analysis is verified by simulation result. This analysis is then applied to record and reconstruct video hologram.

Digital holography has many advantages in comparison with the conventional hologram. The optical field of object can be recorded and stored in digital devices. Hence one we can transfer and use it anytime and anywhere. The digital hologram is moving to the applications in real life such as holographic displays. However the method to record a moving object is still developing. There are several methods to record moving object. Among them, off-axis and parallel phase-shifting in-axis digital hologram are two well known methods. The condition for clear reconstruction in these holograms must be studied carefully. In this paper, we present an analysis on the imaging property of digital holography using space bandwidth product. Our analysis can be applied to both of record and reconstruction of video hologram. The parallel 2-step phase-shifting method is used to record in-line video hologram. A SLM is used to modulate phase of reference beam to two different phase steps. The two neighboring pixels in SLM are modulated with phase 0 and 90 degrees, and then a lens system is used to mapping the phase distributed behind the SLM to CCD camera. So, two step phases hologram can be recorded at the same time.

8384-42, Poster Session

3D resolution in computationally reconstructed integral photography

M. Martinez-Corral, G. Saavedra-Tortosa, H. Navarro, Univ. de València (Spain); Z. Kavehvash, K. Mehrany, Sharif Univ. of Technology (Iran, Islamic Republic of); S. R. Bagheri, Philips Research North America (United States)

n this research we have proposed a new definition for three-dimensional (3-D) integral imaging resolution. The general concept of two-dimensional (2-D) resolution used also for 3-D is failed to describe the 3-D resolvability completely. Thus, the researches focused on resolution improvement in 3-D integral imaging systems, didn't investigate thoroughly the effect of their method on the 3-D quality. The effect has only been shown on the 2-D resolution of each lateral reconstructed image. The newly introduced 3-D resolution concept has been demonstrated based on ray patterns, the cross-section between them and the sampling points. Consequently the effect of resulting sampling points in 3-D resolvability has been discussed in different lateral planes. Simulations has been performed which confirm the theoretical statements.

8384-43, Poster Session

Experiments on axially distributed three-dimensional imaging techniques

E. P. Flynn, B. Javidi, Univ. of Connecticut (United States)

We will display new techniques to exploit three-dimensional image reconstruction using Axially Distributed Sensing (ADS).

Test environments such as controlled laboratory, outdoor scenes, and computer generated platforms will be explored.

8384-44, Poster Session

Three-dimensional stereoscopic display system on the table-top

K. Yoon, H. Lee, S. Kim, Korea Institute of Science and Technology (Korea, Republic of)

3D Display is generally designed to show 3D stereoscopic image to viewer at the center position of it. But, some interactive 3D technology needs to interact with multiple viewers and each stereoscopic image such as an imaging demonstration. In this case, the display panel on the table is more convenient for multiple viewers. In this paper, we introduce the table-top stereoscopic display that has the potential to combine this interactive 3D technology. This display system enables two viewers to see the other images simultaneously on the table-top display and each viewer to stereoscopic images on it. Also, this display has first optical sheet to make multiple viewers see each image and second optical sheet to make them see stereoscopic images. We use commercial LCD display, design the first optical sheet to make two viewers see each image, and design the second optical sheet to make each viewer see each stereoscopic image. The viewing zone from our display system is designed and easy to be viewed from children to adult to look at three dimensional stereoscopic images very well. We expect our 3D stereoscopic display system on the table-top can be applied for the interactive 3D display applications in the near future.

8384-45, Poster Session

Method of crosstalk reduction using lenticular lens

H. Lee, Yonsei Univ. (Korea, Republic of) and Korea Institute of Science and Technology (Korea, Republic of); K. Lee, S. Kim, Korea Institute of Science and Technology (Korea, Republic of)

Generally non-glass type three dimensional stereoscopic display systems should be considering human factor. Human factor include the crosstalk, motion parallax, types of display, lighting, age, unknown aspects around the human factors issues and user experience. Among these human factors, the crosstalk is very important human factor because; it reduces 3D effect and induces eye fatigue or dizziness. In these reason, we considered method of reduction crosstalk in three dimensional stereoscopic display systems. In this paper, we suggest method of reduction crosstalk using lenticular lens. Optical ray derived from projection optical system, converted to viewing zone shape by convolution of two apertures. In this condition, we can minimize and control the beam width by optical properties of lenticular lens (refractive, pitch, thickness, radius of curvature) and optical properties of projector (projection distance, optical features). In this processing, Gaussian distribution type shape is converted to rectangular distribution type shape. According to the beam width reduction will be reduce crosstalk, and it was verified used to lenticular lens.

8384-46, Poster Session

Imaging characteristics of holographic stereoscopic 3D projection display

H. Kim, Korea Univ. Sejong Campus (Korea, Republic of); Y. Park, Electronics and Telecommunications Research Institute (Korea, Republic of); H. Kim, Chungbuk National Univ. (Korea, Republic of); B. G. Chae, J. Nam, J. Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

Recently holographic 3D display technology is actively researched and its technology potentials are rediscovered with advances in device fabrication and high performance computation technologies. Holographic display forms a continuum of voxels on a curved surface representing

3D scene in free space and then observes can see natural 3D scene with perfect depth perception cues such as accommodation, motion parallax, convergence, and binocular disparity.

In principle, the holographic 3D display is a perfect solution for 3D display, but its digital realization is hindered by several practical limitations in devices, systems, and content generation. For digital holographic 3D displays, we can raise two main technological issues; enhancing viewing angle and image size enlargement. These two factors have an inherent trade-off relationship with a finite space-bandwidth product of spatial light modulator. For large aperture imaging, the viewing angle should be inevitably sacrificed and for large viewing angle, the image size must be reduced. Wise use of this finite resource has been actively researched and quite good display configurations were reported.

In this paper, we propose a design of 10inch (large aperture) holographic stereoscopic 3D projection display. The proposed structure has very narrow viewing angle, but, by employing the stereoscopic 3D display concept by building two beam lines for two separated human eye pupils, successfully realize holographic 3D images with binocular disparity. The volume imaging characteristics are analyzed and several problematic issues of the proposed system are extracted and the possible approaches for image quality enhancement are discussed.

8384-47, Poster Session

Computer generated hologram of deep 3D scene from the data captured by integral imaging

K. Wakunami, M. Yamaguchi, Tokyo Institute of Technology (Japan); B. Javidi, Univ. of Connecticut (United States)

We introduce hologram calculation for real object/scene using ray-sampling (RS) plane from a set of elemental images obtained by integral imaging technique. In integral imaging display, due to the influence of ray sampling on the lenslet array and diffraction at the lenslet aperture, the resolution of reconstructed images is limited. In our approach, we use virtual RS plane located near the object and light-rays coming from target object is resampled with higher density from a set of elemental images by using image based rendering (IBR) technique (that is a free-viewpoint image synthesis technique from multi-view images). Then ray information is transformed into the wavefront based on the angular spectrum theory at the RS plane, and the wavefront propagation from the RS plane to the CGH is calculated. Because final image quality by our approach is affected by accuracy of resampling process, proper IBR technique should be employed with consideration for the parameter of input images and target scene property. In this report, light field rendering (LFR) technique that is one kind of IBR techniques and that permits to render a free-viewpoint image by simply using a single plane called focal plane to approximate the object space, was used for resampling process. Experimental result shows that deep 3D scene composed of plural objects at different depths can be reconstructed with order of magnitude higher resolution by proposed technique compare with conventional integral imaging display.

8384-19, Session 5

An overview of 3D visualization with integral imaging in photon starved conditions

A. Stern, D. Aloni, Ben-Gurion Univ. of the Negev (Israel); B. Javidi, Univ. of Connecticut (United States)

Recently it was demonstrated that there-dimensional (3D) object recognition and visualization is possible with integral imaging in photon counting condition or under very low illumination conditions. We present an overview of reconstruction techniques, imaging performance and compressive sensing ability of 3D integral imaging in photon starved condition.

8384-20, Session 5

Improved resolution in far-field integral imaging

M. Martinez-Corral, H. Navarro, G. Saavedra-Tortosa, A. Dorado, Univ. de València (Spain); B. Javidi, Univ. of Connecticut (United States)

In multi-view three-dimensional imaging, to capture the elemental images of distant objects, the use of a field-like lens that projects the reference plane onto the microlens array is necessary. In this case, the spatial resolution of reconstructed images is equal to the spatial density of microlenses in the array. In this paper we report a simple method, based on the realization of double snapshots, to double the 2D pixel density of reconstructed scenes. Experiments are reported to support the proposed approach.

8384-21, Session 5

One-dimensional integral imaging based on parallax image's virtual reconstruction

Q. Wang, H. Deng, Sichuan Univ. (China)

One-dimensional integral imaging based on parallax image's virtual reconstruction is proposed, which contains parallax image's virtual reconstruction process and one-dimensional elemental image array's capture process. The parallax image's virtual reconstruction is an inverse process of the capture of parallax images, and a virtual three-dimensional (3D) scene which is just the same as the original 3D scene is reconstructed. In the one-dimensional elemental image array's capture process, a lenticular sheet is used to pick up the reconstructed virtual 3D scene. Each lenticular lens has its own perspective to the virtual 3D scene, and a one-dimensional elemental image array is obtained on the focal plane of the lenticular sheet.

A pixel mapping algorithm is deduced to implement the parallax image's virtual reconstruction and one-dimensional elemental image array's capture processes, and a one-dimensional elemental image array is generated by the mapping of pixels on parallax images obtained by a one-dimensional camera array. The depth of the displayed 3D scene can be adjusted by changing the distance L between the parallax barrier and the lenticular sheet in the pixel mapping algorithm. Assume that the distance between 3D object and camera is l. When $l = L$, the 3D object will be displayed on a screen, If $l > L$ or $l < L$, the 3D object will be displayed behind of or in front of a screen. The experimental results demonstrate that the displayed 3D scene restores its original size and depth as the conventional integral imaging does.

8384-22, Session 5

Functional three-dimensional imaging based on integral imaging technique

J. Park, Chungbuk National Univ. (Korea, Republic of)

Integral imaging captures and reconstructs spatio-angular ray distribution, or also called light ray field using an array of pinholes or lenses. Since the three-dimensional information of the object scene is embedded in the light ray field, it is possible to capture or reconstruct the three-dimensional information of the object using integral imaging technique.

In this report, we introduce a few application of the integral imaging to three-dimensional capture. It is well known and widely used to synthesize orthographic view images of the object from the light ray field captured by integral imaging. Computational integral imaging reconstruction which synthesizes re-focused image at a given distance is also widely used. In addition to these techniques, we introduce two new additional functionality of the integral imaging three-dimensional capture.

First addition is depth selective capturing capability. In conventional capturing, whole three-dimensional scene in the field of view of the imaging system is captured. Frequency domain analysis of the captured light ray field, however, enables filtering operation of the captured information based on distance from the lens array. This feature allows selection or rejection of specific depth range in the captured three-dimensional information. Structured illumination on the object scene can further enhance the depth discrimination ratio of the depth filtering operation. Along with the principle, the effect of the occlusion will also be explained in the presentation.

Second addition is hologram synthesis. Conventional hologram capturing requires coherent interferometer, which makes the capturing process complicated and limited in application. Integral imaging based method enables hologram synthesis from the incoherent capturing, simplifying the hologram capture process greatly. The limited space-bandwidth-product can be enhanced by capturing multiple sets of the light field or using lens arrays with higher spatial density. The principle and the recent experimental results will be presented.

8384-23, Session 5

Integral imaging system with enlarged horizontal viewing angle

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We present a three-dimensional (3-D) imaging system with an enlarged horizontal viewing angle in integral imaging. In our proposed method, we control the ratio of the horizontal to vertical viewing angle by tilting the lens array which is used in a conventional integral imaging system. In integral imaging, a horizontal and vertical viewing angle depends on a width and height of an elemental image and a focal length of an elemental lens. Therefore, we change the ratio of the width to height of the elemental image in order to control the ratio of the horizontal to vertical viewing angle. The ratio of the width to height of the elemental image depends on the tilt angle of the lens array. We developed a capture and a display system with an enlarged horizontal viewing angle. Here, we arranged the elemental image with the width which was larger than the pitch of the elemental lens in order to enlarge the horizontal viewing angle compared with that in a conventional method. We conducted an experiment to capture and display the 3-D images, and confirmed the validity of the method.

8384-24, Session 5

Automatic target recognition of 3D objects under photon starved condition using advanced correlation filters

M. Cho, Univ. of Connecticut (United States); A. Mahalanobis, Lockheed Martin Missiles and Fire Control (United States); B. Javidi, Univ. of Connecticut (United States)

In this paper, an overview of automatic target recognition for three-dimensional (3D) passive photon counting integral imaging system using maximum average correlation height filters is presented. Poisson distribution is adapted for generating photon counting images. For estimation of the 3D scene from photon counting images, maximum likelihood estimation is used. The advanced correlation filter is synthesized with ideal training images. Using this filter, we prove that automatic target recognition may be implemented under photon starved conditions. Since integral imaging may reduce the effect of occlusion and obscuration, the advanced correlation filter may detect and recognize a 3D object under photon starved environment. To demonstrate the ability of 3D photon counting automatic target recognition, experimental results are presented.

8384-25, Session 6

3D shape measurement using deterministic phase retrieval and a partially developed speckle field

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In an iterative phase retrieval technique, speckle effect offered an enabling step for the enhanced reconstruction of smooth test wavefronts [1-3]. A smooth wavefront is first converted into a speckle field by placing a photoresist phase-type diffuser in the optical path. Worth noting is the fact that the speckle field has a special property that, aside from a scattered wave component, it contains an unperturbed wave component [4], i.e., a partially-developed speckle field (PDSF). When the unperturbed incident light, usually a plane wave, interferes with the scattered light, the result is a rapidly varying intensity.

One drawback of the iterative speckle phase retrieval technique, however, is the extended time to generate the multiple measurements (usually 20) [4]. Thus, it cannot be used in real-time applications. A significant innovation is the use of a spatial light modulator (SLM) facilitating rapid single-plane speckle recording [5]. Automated correction of setup misalignments using the SLM technique permits reduction of the number intensity measurements [6]. A challenge would be to reduce further the number of measurements to a minimum of 2 speckle patterns, thereby allowing the possibility of simultaneous data gathering. Requiring only 2 intensity measurements, deterministic phase retrieval [7], to our knowledge, has not been demonstrated in conjunction with a PDSF.

Figure 1 shows a schematic of the technique. Implementation using SLM setup is described in [5]. A plane wave (wavelength, = 532 nm) is incident on a phase diffuser (tuned at 532 nm) and the generated speckle field illuminates the test object (lens, f = 15 cm). The effective distance between measurement planes is 3 mm. The phase map is directly calculated using the 2 speckle patterns and the pure-phase approximation to the transport of intensity equation [8].

Figures 2(a) and 2(b) are sample intensity measurements. Figure 2(c) shows a plot proportional to the intensity derivative. Figure 2(d) shows the retrieved spherical phase map of light from the lens object. The phase map is wrapped in 2 and is scaled relative to the background phase distribution such that the concentric circular phase map and the 3D shape are evidently revealed [Fig. 2(e)].

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8384-26, Session 6

Three-dimensional imaging and visualization of camouflaged objects by use of axially distributed sensing method

D. Shin, B. Javidi, Univ. of Connecticut (United States)

In this paper, we present an overview of three-dimensional imaging and visualization of camouflaged objects using axially distributed sensing. The axially distributed sensing method collects three-dimensional information for a camouflaged object. Using the corrected elemental images, three-dimensional slice images are visualized using the digital reconstruction algorithm based on inverse ray projection model. In addition, we introduce the analysis of the depth resolution in our axially distributed sensing structure. The optical experiments are performed to capture longitudinal elemental images of a camouflaged object and to visualize the three-dimensional slice images with digital reconstruction.

8384-27, Session 6

New synthesizing 3D stereo image based on multisegmented method

W. Ham, L. Badarch, E. Tumenjargal, H. Kwon, Chonbuk National Univ. (Korea, Republic of)

In this paper, we introduce the hardware/software technology used for implementing 3D stereo image capturing system which was built by using two OV3640 CMOS camera modules and camera interface hardware implemented in S3C6410 MCP.

We also propose multi-segmented method to capture an image for better 3D depth feeling. An image is composed of 9 segmented sub-images each of which is captured by using two degree of freedom DC servo per each left and right CMOS camera module for the improving the focusing problem in each segmented sub image. First we analyze the disparity data of each sub-image and then we compensate disparity data and synthesize the whole image. We hope and sure that this new method will improve the comfortable 3D depth feeling even though its synthesizing method is a little complicate.

We developed device driver for CMOS camera module based on WinCE OS (operating system) because the size of kernel of WinCE OS is small and suitable for developing mobile embedded 3D stereo image capturing system. We capture 9 left/right sub-image under the precise control of DC servo for synthesizing two left and right of the whole image . We calculate the disparity of each sub-image and compensate its disparity and deciding its corresponding disparity data in a whole image. This idea may improve the comfortable 3D depth feeling. We will propose the compensation method of disparity in this paper.

8384-28, Session 6

SSVEP-based BCI for manipulating three-dimensional contents and devices

S. Mun, M. Park, Korea Institute of Science and Technology (Korea, Republic of); M. Whang, Sangmyung Univ. (Korea, Republic of)

SSVEP-based BCI(brain computer interaction)s are primarily utilized in HCI (human computer interaction) field because of its fast data processing and minimal training time. The purpose of this study is to identify the possibility of applying SSVEP (steady state visual evoked potential) to 3D (three dimensional) interaction and to propose a reliable 3D manipulating system for severely impaired people. This study is novel and meaningful in the following three ways. First, severely disabled people with no other ways to communicate need to control home appliances and other equipment like wheelchairs, prosthetics, and orthotics. A lot of studies have been done to help the people manipulate electronic devices in 2D space but less in 3D environment that recently becomes vigorous in the development of contents industry and devices industry. In this study, we propose a new 3D navigation system in an effort to help the disabled people communicate with real world as well as not-disabled people who want to remotely control electronic devices. Second, we apply a simple algorithm to translating the SSVEP signal into output controls, using the characteristics of the flicker harmonic phenomena. Six flicker frequencies are used to control a cursor in six directions (x, y, and z axes). Last but not least, the SSVEP based 3D navigation system proposed in this study may give light to new interaction methods in three dimensional contents and devices effective and efficient to both non-disabled people and the disabled.

8384-29, Session 6

Real-time embodiment of the multiview images having corrected and scaled depth sense in any types of autostereoscopic 3D display system

K. Lee, S. Chun, S. Kim, Korea Institute of Science and Technology (Korea, Republic of)

In this paper, we suggested the adaptable correct depth sense making process in real-time streaming to the multi-view auto-stereoscopic 3D display system. The key of the suggestion is that the real-timing embodiment of right scaled depth without a depth distortion to be possible in any types of stereoscopic circumstances by using a recomposed hybrid object space based on the actual images taken by both Z-depth camera and virtual cameras within the calculation. The process is consisted with two parts. Firstly, the distorted object space is designed to provide both the right scaled depth sense keeping a size homeostasis and the corrected depth sense compensating depth distortion of the displayed object image to the observer, whether what the types of 3D displays are used in. Secondly, the multi-view images are created and merged by the number of virtual cameras, which user’s requirement to display them. Consequently, we had taken the result that the frame rate of 5-views at stereoscopic circumstance either an office (19”) or a mobile (2.8”) is obtained with 2~3 fps in a personal computer environment. In both, the reconstructed multi-view images are shown they have an exactly same property such as an image size, a scaled ratio and the corrected depth sense. This matter shows the capability of our investigation that the raw depth data included distorted object space can be transferred freely to user’s multi-view images for any types of stereoscopic 3D displays such as “Hop-in systems”. To increase the frame rate, multiple graphic process units are needed.

8384-30, Session 7

3D visual guidance interface for industrial operations

K. G. Harding, G. Abramovich, C. Nafis, GE Global Research (United States); A. Vemury, U.S. Dept. of Homeland Security (United States)

Many operations that are done manually can be difficult to instruct to someone working in an unstructured environment that is not already familiar with the operation. The standard practice is to use 2D pictures that many find hard to follow or interpret within the 3D volume of the working environment. Cues such as perspective and parallax that people use in every day life are lost. Flat video views become an exercise in manual coordination of what the user sees on a screen to what they see before them. We have explored a variety of visual aids that might be used guidance in three-dimensions for manual operations. These methods include simulated 3D images, as well as direct methods that provide a live view of the operation as the user works in 3D space. This paper will explore some of the pros and cons of these methods, and present some very preliminary results that suggest future directions for this work.

8384-31, Session 7

Cylindrical liquid crystal lenses system for autostereoscopic 2D/3D display

C. Chen, Y. Huang, P. Wang, National Chiao Tung Univ. (Taiwan); C. Tsai, Industrial Technology Research Institute (Taiwan)

The liquid crystal lenses system, which could be electrically controlled easily, for autostereoscopic 2D/3D switchable display was proposed. Some proposed LC lens would be described in this paper. The multi-electrode based LC lens could provide good focusing ability by applying suitable voltage on each electrode although its response time was still too slow to switch on/off (~10sec.). Thus, the improved Fresnel based LC lens and specific driving method called dual-directional overdriving method were proposed as well. The above methods could reduce the switching time by reducing the cell gap or by applying large voltage onto cell respectively. Consequently, the switching time could be further reduced to 0.8 sec. In addition, another improved LC lens which only utilized less controlled electrodes and coated a high-impedance layer inside the cell was proposed. The smooth electric-potential distribution within the LC layer could be formed under driving status. Thus the device has less device complexity, low driving voltage, and good optical performance also could be obtained It is believed that the LC lens system has high potential in the future.

8384-32, Session 7

Inexpensive robust 3D reconstruction using multisensor signals

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In this paper, we present a novel approach to build inexpensive, robust 3D registration algorithm. 3D reconstruction plays vital role in many vision applications. But the accuracy of building 3D reconstruction costs expensive by using different sensors like GPS or INS. Our algorithm consists of two steps. As a first step, we introduce a novel search algorithm by fusing LiDAR data with polarized image. This is done by searching corresponding lines using Hough transform between LiDAR data and polarized image.The overall goal is to determine the crude estimate of the camera matrix. In second step, we refine the camera matrix by adding the sound signals (i.e sound signals corresponds to visual image) to the camera matrix. The results are promising compared to existing techniques.

8384-33, Session 7

Measurement methods with moving image sensor in autostereoscopic display

S. Yoon, S. Kim, Korea Institute of Science and Technology (Korea, Republic of)

Generally, auto-stereoscopy has a restriction as a fusible stereo condition. In addition, a viewer keeps a constant viewing distance. It is called optimum viewing distance (OVD).

The previous measurement methods that measure the characteristics of the auto-stereoscopic display have problems. The first reason is measures only luminance of the small area. Second reasons, projection area changes with the rotation of the measuring equipment.

In this paper, we proposed on image sensor method for measures to auto-stereoscopic display. This method is measuring the intensity distribution in the all area of the panel, but other methods to measuring luminance of a limited area. This method needs two data types. The first type is black or white image about all viewpoints. The second data type each of viewpoint color is white and other viewpoints color is black.

12-viewpoint auto-stereoscopic display was measured by this method. As a result, we obtain intensity distribution, optical path, and width of viewpoint for each viewpoint. Therefore we can find the OVD of auto-stereoscopic display.

We can find the intensity distribution in correct OVD used by this method. In addition, we make sure the viewable area and this area includes OVD. This method is applied to the stereoscopic display.

8384-34, Session 8

Viewing zones of IP and MV

J. Son, Konyang Univ. (Korea, Republic of); M. Park, Korea Institute of Science and Technology (Korea, Republic of); H. Lee, Yonsei Univ. (Korea, Republic of); J. Nam, W. Son, Electronics and Telecommunications Research Institute (Korea, Republic of)

The viewing zone characteristics of Multiview 3-D imaging methods based on Integral Photography(IP) and a typical multiview image arrangement(MV) are analyzed. It has been considered that the viewing zones are different for the methods and there are several separated viewing zones are formed in each method. But the viewing zones of IP and MV are not different except IP viewing zone is barely extended to a first half of that of MV. By this reason, there may not be in IP any viewing regions having the similar characteristics as those for individual view images in MV. The central and side viewing zones in these methods are not independent to each other. The image in each pixel cell projected to the side viewing zones assists to make that projected to the central viewing zone a complete image scene. In geometrical optics point of view, IP and MV have the optical geometry of Parallel and Radial projection geometry. This difference hasn't been considered seriously. However, this difference brings distinctive differences between two methods.

In this paper, the viewing zones of the two methods are compared and image characteristics of different viewing regions of the viewing zones are compared. Since the optical geometry of IP and MV are not too different from that of the reconstructed image geometry of 2-dimensional stereo hologram, this analysis can also be effective in investigating the image compositions of the hologram in various viewing places.

8384-35, Session 8

Crosstalk minimization in multiveiw 3D display by eye tracking and viewpoint fusion

S. Kim, S. Yoon, K. Yoon, Korea Institute of Science and Technology (Korea, Republic of)

Nowadays the share of eyeglasses type 3DTV is increasing rapidly but the need of wearing special eyeglasses is uncomfortable for 3DTV watchers. Therefore autostereoscopic 3D display and 3DTV will appear in mass market in future but there are many problems in multiview type autostereoscopic 3D display like crosstalk, restriction of viewer position, resolution decrease, eye fatigue problem, and etc. Among those problems, the crosstalk is very serious problem because it reduces 3D effect and induces eye fatigue or dizziness. Therefore we designed a novel method of minimization of crosstalk in multiview 3D display by viewpoint fusion when an eye tracking system is applied to multiview 3D display. A crosstalk minimization multiview 3D display is developed and experimental test gives low crosstalk at the level of eyeglasses type 3D display. And this method is effective for mass-commercialization of autostereoscopic 3D display.

8384-36, Session 8

fVisiOn: glasses-free tabletop 3D display to provide virtual 3D media naturally alongside real media

S. Yoshida, National Institute of Information and Communications Technology (Japan)

This paper introduces a novel, glasses-free tabletop 3-D display, named fVisiOn. The display floats virtual 3-D objects on an empty, flat, tabletop surface and enables multiple viewers to observe the raised 3-D images from any angle at 360-degrees. Our 3-D image reproduction method employs a combination of an optical device and an array of projectors. It is installed beneath the table to keep the tabletop area clear and produces continuous horizontal parallax in the direction of a circular path located above the table. In the latest prototype, a virtual girl of height 5-cm dances on the table energetically.

8384-37, Session 8

3D display crosstalk simulator system based on mixed reality

M. Park, H. Lee, Korea Institute of Science and Technology (Korea, Republic of); J. Lee, Korea Institute of Science and Technlology (Korea, Republic of); J. Son, Konyang Univ. (Korea, Republic of)

Generally human factors are used to make systems safe, efficient, and comfortable for humans on the basis of knowledge about humans' abilities and limits. To minimize undesirable biomedical effects viewers' attributes, visual contents, viewing environments, display, and device factors are investigated. Studies show that crosstalk causes distortions, reduces image quality and visual comfort, and increases perceived workload. Moreover, there is evidence that crosstalk effects depth perception from disparity. Also, crosstalk causes serious fatigue, headache, eyestrain and etc. Thus, it is very important to minimize crosstalk and compute light intensity to improve the quality of the display system.

In this paper, we propose a 3D display crosstalk simulator system based on MR(Mixed Reality). Proposed simulator system calculates light distribution using several parameters such as the number of barrier, the number of aperture, light distribution, crosstalk and observation area along the z axis by some parameters such as the size of display, resolution, viewing distance from the parallax barrier, view points, inter distance between the display plane and the parallax barrier, width of a unit pixel, width of an electrode, binocular distance and etc. After the calculation, the simulator projects the light distribution onto the ground from the top of the viewing zone. Projected light distribution is scaled to the corresponding display size. Thus, the viewer experiences the real light distribution in the real space like living room. This simulator system make it possible to design and measure light distribution finding out optimized viewing zone without implementing the display.

8384-38, Session 8

ATSC 8-VSB and M/H hybrid 3DTV system development for terrestrial broadcasting services

S. Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

This paper presents 8-VSB & M/H hybrid 3DTV system for ATSC terrestrial 3DTV broadcasting services.

The system transmits MPEG-2 encoded left images through HD main channel(8-VSB) and H.264 encoded right images through mobile channel(M/H) simultaneously.

Basically hybrid 3DTV support stereoscopic 3D HD services by mixed quality left/right images for 3D image rendering.

For the more comfortable 3D service providing & considering human factors under hybrid 3DTV service environment, we also propose new enhancement video processing technologies with small amount of disparity map information.

In this paper, we propose 8-VSB & M/H hybrid 3DTV system which is support stereoscopic 3D HD, 2D HD fixed and 2D mobile concurrent broadcasting within 6MHz bandwidth and the system could allow maximum channel flexibility & extended service functionalities as well as fully backward compatible with current ATSC A.153

8385-01, Session 1

Single frequency fiber laser for external volume Bragg resonator

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We are reporting on a single frequency pulsed fiber laser based on extremely narrow band volume Bragg gratings (VBGs) recorded in photo-thermo-refractive (PTR) glass [1]. Reflective Bragg gratings with spectral bandwidth about 10 GHz were specially developed and used in a Yb doped fiber laser setup with a cavity length of about 1 m. This fiber laser is actively Q-switched. The usage of newly developed VBGs enforced its operation in stable single TEM00 transverse mode and single longitudinal mode. It generates pulses of 100 - 200 ns duration at a repetition rate of 1 - 100 Hz and pulse energy of ~50 µJ, limited by the onset of stimulated Brillouin scattering that leads to fiber fracture.

Traditionally based on Distributed Feedback- (DFB) or Distributed Bragg- Reflectors (DBR), single frequency fiber lasers provide high stability and narrow spectral linewidth. However, with a cavity length of less than 5 cm, their CW output power is limited to a few hundred mW and in Q-switched operation their pulse energy is typically < 1 µJ [2]. Subsequent fiber amplifiers can be used to increase the pulse energy to the hundred µJ level and a record 126 µJ pulse energy has been reported from a three stage amplifier with specialty fiber and large core end stage [3].

Here we report on a master oscillator with 50 to 100 µJ of pulse energy with no further amplification. The laser medium is commercial large mode area Yb doped fiber with core diameter of 20 µm.

8385-02, Session 1

Frequency up-conversion detection system for space-based lidar

I. B. Zotova, ArkLight, Inc. (United States); Y. J. Ding, Lehigh Univ. (United States); N. S. Prasad, NASA Langley Research Ctr. (United States)

During this invited talk, we will summarize the recent progress being made so far on the detection of infrared radiation in the vicinity of 1.6 microns based on frequency up-conversion in nonlinear-optical waveguides. Such a process is capable of reaching the single-photon detection limit. The corresponding compact and portable detection system reaching such a limit will have variety of applications.

8385-03, Session 1

Polarization maintaining coherent fiber bundle

S. Jiang, AdValue Photonics, Inc. (United States)

Monolithic polarization maintaining fiber bundle can be used for imaging especially integrated with complementary metal oxide semiconductor (CMOS) image sensor, for high resolution two-photon microscope, and for volumetric endoscopic coherence microscopy. Polarization maintaining single mode fiber coherent bundle can act as an array of both amplitude and wavefront spatial filters for both astronomical and Earth sciences applications.

We studied the fabrication process of monolithic polarization maintaining single mode fiber bundle using silicate glasses. Silicate core glass, cladding glass and stress inserting glass were designed and fabricated. We used rod-in-tube technique to fabricate the fiber preform. Core glass rods, stress inserting rods, and cladding glass tube with square external configuration were fabricated. Core glass rods and stress rods were drilled from bulk glasses using diamond embedded core drill. The barrel of these rods was polished to high surface quality. The holes of the cladding glass tube were drilled with core drill, and the external square configuration was machined with surface grinder. Both inside and outside surfaces of the cladding glass tube were polished to a high surface quality.

The fiber was pulled at our own fiber drawing tower. We draw the fiber with high tension in order to ensure the square external configuration is maintained. No plastic coating was used during fiber drawing process. To the best of our knowledge, it is the first demonstration of PM monolithic coherent fiber bundle array with 16 cores. It also represents the highest number of cores in any PM fiber.

8385-04, Session 1

Metal-mesh optical filter technology for mid-IR, far-IR, and submillimeter

W. R. McGovern, P. R. Swinehart, E. L. Hogue, Lake Shore Cryotronics, Inc. (United States)

Many types of sensing, for target identification, tracking and chemical and biological detection are much more effective if at least a portion of the optical spectrum can be eliminated. In many of these applications, the physical robustness, and high transmission of the metal-mesh filters can prove very advantageous. Further, these types of filters are of great use in industrial and scientific instrumentation. Astronomy, environmental monitoring, free-electron lasers, EMI shielding, and IR / Thz spectroscopy are examples of applications that can benefit from metal-mesh filters.

Other thick multilayer dielectric filters suffer from problems stemming either from the lack of materials that are transparent, radiation-hard, cryogenic-tolerant, stable and compatible with each other at IR/Thz wavelengths or from poor control over the pass band.

We will show Frequency Selective Surfaces (FSS) used to shape spectral energies for band-pass, long-pass and polarizing applications, as well as blocking unwanted out-of-band radiation. We will present data on vibration tolerant, launch-capable, compact, lightweight, high-transmission radiation-hard filters operating at cryogenic temperatures over center wavelengths from 9 um to 337 um.

8385-05, Session 1

Low-noise, UV-to-SWIR broadband photodiodes for large-format focal plane array sensors

A. Joshi, S. Datta, Discovery Semiconductors, Inc. (United States)

Broadband focal plane array sensors, operating in the 0.25 to 2.5 um wavelength range, are an enabling technology for a myriad of imaging applications. The utility of detecting light from ultra-violet (UV) to short wave infra-red (SWIR) stems from the range of chemical bond energies, and corresponding photoluminescence and absorption spectra of typical materials. For example, organic compounds with conjugated carbon bonds display strong absorption in wavelengths ranging from 0.2 to 0.8 um; whereas, small carbon based molecules such as CH_4, CO, and

CO_2, have spectral signatures in the 1.5 to 2.5 um wavelength range. Applications of hyper-spectral imaging range from determination of various air pollutants and greenhouse gases to flame characterization. Advances in UV-to-SWIR imaging also impact detection of X-rays, gamma rays, and high energy particles by expanding the range of usable scintillators, thereby contributing to bio-medical applications, astronomy, and high-energy physics.

Currently, separate image sensors are used for different spectral sub-bands: GaN for UV, Si for visible, and InGaAs for IR, requiring expensive component-level integration for hyper-spectral imaging. Moreover, the size of the InGaAs focal plane arrays is limited by that of the InP substrate. We present a single image sensor with 0.25 to 2.5 um spectral range using GaAs substrate. The lattice-mismatched photodetector structure addresses key challenges, namely achieving low noise performance in conjunction with high UV efficiency. Availability of commercial GaAs substrates in diameters as large as 6 inches ensures manufacturability of large-format focal plane array sensors.

8385-06, Session 1

Near-infrared silicon, resonant cavity RC-GPD and ROIC arrays

S. A. Vasile, R. Murphy, J. Lipson, aPeak, Inc. (United States); S. M. Unlu, Boston Univ. (United States)

Resonant cavity quantum efficiency enhancement for NIR detection (1030-1064nm) in silicon detectors has been extensively reported over the last several years. The cavity thickness and uniformity has been achieved mainly by using SOI as starting material. Though this approach yields excellent response uniformity, it lacks the flexibility of controlling the tuning wavelength and it is not suitable for processing in standard CMOS or BiCMOS technology.

Silicon Geiger avalanche Photodiode (GPD) technology with its single-photon sensitivity and nanosecond integration time has seen accelerated development worldwide due to increased availability and lower cost of silicon processing. However, the technology of fabricating large GPD arrays is being developed at lower pace, mainly due to the need to customize the readout circuitry (ROIC) to the application (counting, ranging or timing). In order to develop low-cost, large arrays of single-photon silicon detectors in NIR we are developing the technology to fabricate in standard CMOS, large GPD arrays with resonant cavity enhancement (RC-GPD arrays), assembled in flip-chip with dedicated ROIC arrays. For manufacturability, processing cost and flexibility reasons, we implement the resonant cavity process at the end of the GPD+ROIC array fabrication.

In 2011, we have reviewed the silicon Geiger avalanche Photodiode (GPD) array technology developed at aPeak and have pointed to the design and technological challenges to achieve uniform quantum efficiency response over large GPD arrays when the cavity is implemented at the backend of the silicon detector fabrication process. In this paper, we present the progress in tuning the resonant cavity over large arrays as well as the functional validation of ROICs designed to operate with the RC-GPD arrays.

Test vehicle RC-GPD arrays assembled in flip chip have been used to verify all the steps of the process flow to implement and control the resonant cavity tuning at the target wavelength. RC-GPD array spectral mapping has been refined and it now allows measuring the resonant wavelength with 50pm resolution and tuning at the target resonant wavelength with 100pm resolution. This performance demonstrates the feasibility of fabricating the resonant cavity at the backend of the GPD array fabrication. The flexibility achieved by tuning the resonance at the pixel level opens the opportunity of tuning adjacent RC-GPD pixels at various wavelengths and may enable hyperspectral capability. We will also review previous results on evaluating the radiation hardness of our silicon GPD array technology (legacy technology used for RC-GPD array technology) in neutron and proton environments. ROIC arrays, designed to operate with our common anode RC-GPD arrays, have been developed in FPGA and ASIC technologies. FPGA ROICs have been validated and the counting and timing performance have been verified. ROICs to operate with 32x32 pixel RC-GPD arrays have been fabricated and passed the static and functional testing. Specifics of the ROIC design and validation will be also presented.

8385-39, Session 1

2µm pulsed fiber laser transmitters based on highly TM-doped germanate fibers for space applications

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In this paper, we report a high pulse energy all-fiber-based ~ 2 m pulsed fiber laser transmitter with transform-limited linewidth and 10-100 ns pulse width. This monolithic MOPA-based pulsed fiber laser is based on the highly Tm-doped germanate fibers, which can be used for space applications, such as LIDAR and laser remote sensing. In our experiments, two kinds of single-frequency pulsed fiber laser seeds were used. One is actively Q-switched fiber laser seed based on fiber birefringence induced by a piezo in the short fiber laser cavity. Another one is directly modulated single-frequency pulsed fiber laser seed by using electro-optic and acoustic-optic modulators. The single-mode large core PM highly Tm-doped germanate fibers 25/250 µm and 30/300 µm were developed. The transform-limited fiber laser pulses in 10-100 ns regime has been successfully amplified by using the newly developed Tm-doped germanate fibers in the power amplifier stages. Based on the monolithic MOPA configuration, ~ 0.95 mJ pulse energy has been achieved, which corresponds to a peak power of > 63 kW for transform-limited fiber laser pulses at ~2 µm regime.

8385-07, Session 2

A low-cost thermal infrared hyperspectral imager for small satellites

S. T. Crites, P. G. Lucey, R. Wright, H. Garbeil, K. Horton, Univ. of Hawai'i (United States)

The growth of the small satellite market and launch opportunities for these satellites is creating a new niche for earth observations that contrasts with the long mission durations, high costs, and long development times associated with traditional space-based earth observations. Low-cost, short-lived missions made possible by this new approach provide an experimental platform for testing new sensor technologies that may transition to larger, more long-lived platforms. The low costs and short lifetimes also increase acceptable risk to sensors, enabling large decreases in cost using commercial off-the-shelf (COTS) parts and allowing early-career scientists and engineers to gain experience with these projects. We are building a low-cost long-wave infrared spectral sensor, funded by the NASA Experimental Project to Stimulate Competitive Research program (EPSCOR), to demonstrate ways in which a university's scientific and instrument development programs can fit into this niche. The sensor is a low-mass, power-efficient thermal hyperspectral imager with electronics contained in a pressure vessel to enable use of COTS electronics and will be compatible with small satellite platforms. The sensor, called Thermal Hyperspectral Imager (THI), is based on a Sagnac interferometer and uses an uncooled 320x256 microbolometer array. The sensor will collect calibrated radiance data at long-wave infrared (LWIR, 8--14 microns) wavelengths in 230 meter pixels with 20 wavenumber spectral resolution from a 400 km orbit. We are currently in the build and assembly stage in preparation for laboratory and airborne testing of the completed instrument in order to demonstrate the spectro-radiometric quality of data that the instrument provides.

8385-08, Session 2

Highly emmissive (0.9999) and highly accurate (0.1 K) blackbody for spaceflight or laboratory use

M. D. Wojcik, H. Latvakoski, M. Watson, S. Topham, Space Dynamics Lab. (United States); M. Mlynczak, NASA Langley Research Ctr. (United States)

Infrared radiometers and spectrometers generally use blackbodies for calibration, and with the high accuracy needs of upcoming missions, blackbodies capable of meeting strict accuracy requirements are needed. Such missions, for example, will measure Earth's emitted spectral radiance from orbit, and will require an absolute accuracy requirement of 0.1 K (3σ) at 220 K over most of the thermal infrared. Space Dynamics Laboratory (SDL) has a blackbody design capable of meeting strict modern accuracy requirements. This design is relatively simple to build, was developed for use on the ground or orbiting spacecraft, and is readily scalable for aperture size and required performance. Similar high accuracy blackbodies are currently in use as a ground calibration unit and with a high-altitude balloon instrument. SDL is currently building a prototype blackbody to demonstrate the ability to achieve very high accuracy, and we expect it to have emissivity of ~0.9999 from 1.5 to 50 μm, temperature uncertainties of ~25 mK, and radiance uncertainties of ~10 mK due to temperature gradients. The high emissivity and low thermal gradient uncertainties are achieved through cavity design, while the low temperature uncertainty is attained by including phase change materials such as mercury, gallium, and water in the blackbody. Blackbody temperature sensors are calibrated at the melt points of these materials, which are determined by heating through their melt point. This allows absolute temperature calibration traceable to the SI temperature scale. Changes in the emissivity of the blackbody are monitored using a quantum cascade laser.

8385-09, Session 2

FalconSAT 7: a CubeSat solar membrane telescope

G. P. Andersen, G. McHarg, M. Dearborn, U.S. Air Force Academy (United States)

Researchers at the US Air Force Academy are currently constructing FalconSAT-7; a CubeSat solar telescope utilizing a unique deployable membrane photon sieve. A photon sieve is a diffractive optical element that consists of many tiny holes in an otherwise opaque substrate. We have demonstrated that these devices are capable of diffraction limited imaging over a narrow bandwidth. As well as being simpler to manufacture and deploy than curved, polished surfaces, the sheets do not have to be optically flat, greatly reducing many engineering issues. As such, the technology is particularly promising as a means to achieve extremely large optical primaries from compact, lightweight packages.

We are demonstrating this technology in a solar telescope that can be deployed from a 3U (30cmx10cmx10cm) CubeSat in low Earth orbit. Our 20cm, f/2 phase photon sieve has 2.5 billion holes range in size from 2-280 microns, patterned on a 25 micron thick polyimide sheet. The membrane is deployed to a flat at the end of a three-armed pantograph truss with tensioning lanyards: all from an initial stowed package just 1U in volume. The final telescope is designed to operate to take images of the Sun at the H-alpha wavelength (656.3nm) for download to a ground station. We are currently constructing an engineering model, with the flight model scheduled to be launched in early 2014.

8385-10, Session 3

Laser ablation-optical cavity isotopic spectrometer for Mars rovers

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A concept of a compact device for analyzing key isotopic composition in surface materials without sample preparation will be presented. This design is based on an advanced modification of Laser Induced Breakdown Spectroscopy (LIBS). First, we developed a method, Laser Ablation Molecular Isotopic Spectrometry (LAMIS) that involves measuring isotope-resolved molecular emission, which exhibits significantly larger isotopic spectral shifts than atomic transitions [1]. Second, we use laser induced plasma to vaporize the sample materials into a plume in which absorption spectra are measured using a tunable diode laser. The intrinsically high spectral resolution of the diode lasers enables accurate measurement of isotopic ratios. The absorption sensitivity can be boosted using cavity enhanced spectroscopy.

Temporal behavior of species in a laser ablation plasma from solid samples with various isotopic composition was studied. Detection of key isotopes associated with signs of life (carbon, hydrogen) as well as strontium and boron in laser ablation plume was demonstrated; boron isotopes were quantified. Many other isotope-resolved molecular spectra were simulated. The experimental results demonstrate sensitivity to Sr-86, Sr-87, and Sr-88 with spectrally resolved measurements for each of them. It is possible to measure strontium isotopes in rocks on Mars for radiogenic age determination. Requirements for spectral resolution of the optical measurement system can be significantly relaxed when the isotopic abundance ratio was determined using chemometric analysis of spectra.

[1]. R.E. Russo, A.A. Bol'shakov, X. Mao, C.P. McKay, D.L. Perry, O. Sorkhabi, Laser Ablation Molecular Isotopic Spectrometry, Spectrochim. Acta B, 66, 99-104; ibid 604-609 (2011).

8385-11, Session 3

Interferometric imaging of geostationary satellites

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Even the longest geosatellite, at ~40 m, subtends only 0.2 arcsec (1 microradian). Determining structure and orientation with sub-meter resolution requires a >30 m diffraction limited telescope at visual wavelengths, or an interferometer. We will describe our Navy Optical Interferometer (NOI) group's efforts to develop interferometric techniques for characterizing, and ultimately imaging, geosatellites. Using the NOI in 2008 and 2009, we were the first to detect a geostationary satellite interferometrically. The NOI observes in 16 spectral channels (500-800 nm) using up to six 12-cm apertures, with baselines (separations between apertures) of 16 to 79 m. We detected the geosatellite DirecTV-9S during "glint" season, using a single 16 m baseline (resolution ~1.5 m). Fringes on longer baselines were too weak because the large-scale structure was over-resolved. The fringe strengths are consistent with a combination of two size scales, ~1 m and > 3 m. Further imaging progress requires measuring both fringe amplitudes and phases, as well as increasing sensitivity. Our near term NOI work is directed toward observing geosatellites with three or more 10 to 15 m baselines, using closure phase measurements to remove atmospheric turbulence effects and coherent data averaging to increase the SNR. Beyond the two- to three-year time frame, we plan to install larger apertures (1.4 and 1.8

m), allowing observations outside glint season, and to develop baseline bootstrapping, building long baselines from chains of short baselines to avoid over-resolution while increasing maximum resolution. Our ultimate goal is to develop the design parameters for dedicated satellite imaging interferometry.

8385-12, Session 3

Noncontact, reagentless, nondestructive, detection of organics, biosignatures, and water

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We present a new active, non-invasive, non-destructive, in situ spectroscopic method that enable a better understanding of the spatial distribution of microbes, organics, and water on natural surfaces that could support life-detection, organic stability assessment, and in-situ resource utilization missions on planetary bodies. Analytical and spectroscopic methods that have been employed to attempt to address these types of questions provide detection over a limited spatial area, provide either significant false positives/false negatives, or are limited to either morphological or chemical information. Furthermore, apart from the spectroscopic analyses, the methods are limited to invasive treatments that alter the samples or remove critical spatial context. Active spectroscopic methods such Raman and or LIBS have been employed as a means to approach these questions however, traditional Raman scattering is an extremely weak phenomenon and LIBS provides looses information regarding chemical structure. As an alternative, we present the use of deep UV native fluorescence, Raman spectroscopy and hyperspectral imaging from proximity (1-10 cm) to standoff (1-5m). Deep UV native fluorescence, coupled to resonance Raman spectroscopy, can provide a solution that has a means to map large areas with sensitivities to organics, that are expected to be present from meteoritic infall, biosignatures indicating extant or extinct life, and detect the presence of water for in-situ resource utilization. The methodology and the data presented will demonstrate the ability to detect and differentiate organics a natural surface - relevant to Mars and other planetary surfaces, and also elucidate the distribution to enable an understanding of their provenance.

8385-13, Session 4

Agile hardware and software system engineering for critical military space applications

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The Multi Mission Bus Demonstrator (MBD) is a successful demonstration of agile program management and system engineering in a high risk technology application where utilizing and implementing new, untraditional development strategies were necessary. MBD produced two fully functioning spacecraft for a military/DOD application in a record breaking time frame and at dramatically reduced costs. This paper discloses the adaptation and application of concepts developed in agile software engineering to hardware product and system development for critical military applications. This challenging spacecraft did not use existing key technology (heritage hardware) and created a large paradigm shift from traditional spacecraft development.

The insertion of new technologies and methods in space hardware has long been a problem due to long build times, the desire to use heritage hardware, and lack of effective process. The role of momentum in the innovative process can be exploited to tackle ongoing technology disruptions and allowing risk interactions to be mitigated in a disciplined manner. Examples of how these concepts were used during the MBD program will be delineated. Maintaining project momentum was essential to assess the constant non recurring technological challenges which needed to be retired rapidly from the engineering risk liens. Development never slowed due to tactical assessment of the hardware with the adaption of the SCRUM technique. We adapted this concept as a representation of mitigation of technical risk while allowing for design freeze later in the program's development cycle. By using Agile Systems Engineering and Management techniques which enabled decisive action, the product development momentum effectively was used to produce two novel space vehicles in a fraction of time with dramatically reduced cost.

8385-14, Session 4

Utilizing low-cost 3U single-sensor satellites for ISR tactical mission capabilities

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Leveraging low cost launch carriers for small satellites with the functionality required for DoD and intelligence missions realizes a hidden potential capability. The Multi-Mission Bus Demonstration (MBD) is a Johns Hopkins University Applied Physics Laboratory program to demonstrate military operational relevance in a 3U cubesat form factor. The MBD spacecraft caters to mission versatility and responsive launch capabilities with a standardized bus and interchangeable payload interface design. MBD embraced the challenge of building two space vehicles on an extremely aggressive timeline and demanding budget, causing the development team to evaluate every step of the process to maximize efforts with minimal manpower and cost. MBD is providing a classified DoD payload capability that is truly operationally relevant and may revolutionize the mission area.

As a single instrument or payload satellite, also called a sensorsat, MBD is a spacecraft of realizable ISR benefits including effective remote sensing, simplified engineering design and program requirements, and reduced time to launch, all yielding an appealing cost per unit. The sensorsat has potential to detect sufficient information that will act as a complimentary component to tactical commanders in heightening battlefield awareness. Recent advancements in technology has put capabilities such as precision navigation, communication intelligence, signal intelligence, tactical warning, environmental intelligence, and a wide variety of ground imaging, at the tip of culmination in a small, economical package. This paper reviews the high functionality of the MBD spacecraft in the miniaturized footprint of 10 cm by 10 cm by 30cm which allows the mission to leverage inexpensive launch opportunities.

8385-15, Session 4

Sensitivity analysis of liquid rocket POGO oscillation characteristic

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Liquid rocket POGO oscillations are a closed-loop interaction between a longitudinal structural mode of vibration and the liquid propulsion system. According to the linear mathematical model of this phenomenon, the sensitivities of liquid rocket POGO oscillation characteristic are studied based on time domain and frequency domain methods. The analytical results show that the degree of influence of the main parameters which are in this POGO system on the frequency characteristic of the liquid propulsion system, the stability and the response of this POGO system. The liquid rocket POGO oscillations can be effectively controlled in term of modifying the highly sensitive parameters.

8385-16, Session 4

A BCI-based humanoid robot system for development of perception and cognition model

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The understanding of how humans process information, determine salience, and combine seemingly unrelated information is essential to automated processing of the large amounts of information that is partially relevant, or of unknown relevance. Recent neurological science research in human perception, and in information science regarding context-based modeling, provides us with a theoretical basis for using a bottom-up approach for automating the management of large amounts of information in ways directly useful for human operators. However, integration of human intelligence into a diagram game theoretic framework for dynamic and adaptive decision support is a very challenging task.

This paper develops a brain-computer-interface (BCI) based humanoid robot system, which can serve as a platform to investigate relationships between complex humanoid robot behaviors and human mental activities that enables decision support amongst a large amount of information. The BCI system can help to validate algorithm performance of control commands through brainwaves between humans and robot systems. The BCI system consists of a data acquisition unit with an electroencephalograph (EEG), a humanoid robot, and a CCD camera. An EEG electrode cup acquires brainwaves from the skin surface on a scalp. The humanoid robot has 20 degrees of freedom (DOFs); 12 DOFs located on hips, knees, and ankles for humanoid robot walking, 6 DOFs on shoulders and arms for arms motion, and 2 DOFs for head yaw and pitch motion. The robot is an executor controlled by human mental activities. The CCD camera takes video clips on the subject's or the instructor's hand postures to identify mental activities which are correlated to the robot walking behaviors. We propose a C-means classification, and a neuro-fuzzy network, to develop a perception and cognition model for integrating human intelligence into a diagram game theoretic framework.

8385-17, Session 4

Control of a robot for minimal impact to the base satellite for capturing a moving object: a contact-dynamics based approach

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Space robots have been successfully used for many manipulation applications such as maneuvering astronauts, berthing and deploying large space structures, constructing and maintaining the International Space Station (ISS), exploring and sample-collecting, satellite on-orbit servicing (technology demos only), etc. In fact, all of these manipulations dealt with well-designed and cooperative payloads and thus, the existing robotics technologies can handle them quite well. However, if a space robot is expected to perform more challenging and riskier tasks, such as to capture an unknown object (e.g., a piece of space debris) or a non-cooperative object (e.g., a tumbling satellite), the currently available space robotics will not be able to accomplish. To make these challenging tasks practical, new enabling technologies have to be developed and tested, from even very basic level. This research is intended to advance one of these enabling technologies.

When a space manipulator intercepts with an external object for capture, the resulting impulse will be transferred along the mechanical arm down to the base satellite causing significant disturbance to the attitude of the base satellite. Such disturbance may destabilize the base satellite if the object is tumbling and the very first interception between the robot tip and the object is not controlled properly. Certainly, such a high risk may be mitigated with a force or impedance control capability of the space robot. However, the implementation of tip force or impedance control usually requires the robot to have a joint torque sensing and control capability which is difficult for a space robot to have. To date, there has never been a really flown space robot having joint torque control capability. Further, even a force or impedance control capability becomes available, much development is still needed before safe capture of a tumbling object in space can be confidently tried. This paper presents a contact-dynamics based optimal motion control strategy for a space robot to have minimal impact to the base satellite during a capturing operation. The idea is to use a contact dynamics model to first predict the contact time and location and then plan an optimal target configuration and speed for the robot to intercept with the tumbling object such that, when the robot touches the tumbling object, it will transfer a minimal angular impulse to the base satellite. The proposed control strategy can be implemented regardless whether the robot has a joint torque control capability or not. Since the control acts before a physical contact happens, it will not affect but actually augment any existing force or impedance control capability of the robot. Simulation examples will be presented to demonstrate the feasibility and effectiveness of the control strategy.

8385-18, Session 5

DataBus-based hybrid routing approach for orbit access networks in lunar exploration

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One of the major challenges for lunar exploration missions is how to achieve dynamic and robust routing. To reduce the development cost, it is desirable to leverage existing technologies, such as routing in mobile ad hoc networks (MANETs) and delay tolerant networks (DTN). However, these technologies are developed for the Earth environment and hence need further investigation for the lunar environment. To support robust access and dynamic mission operations, we propose a DataBus-based Hybrid Routing (DBHR) approach that combines MANET reactive routing protocol (such as AODV) and DTN-based bundle delivery. Our DBHR approach is designed for a tiered architecture where remote nodes communicate with upper-tier gateways through data carriers (DataBus) using short-range radio interfaces. Our scheme explores the (non)availability of the end-to-end path between two peers using MANET routing and provides diverse route options based upon different parameters. This interaction between hop-by-hop DTN technologies and end-to-end MANET protocol will result in a reliable and robust routing protocol for orbit access and improve the overall communication capabilities. To evaluate its performance, we implemented our proposed scheme on commercial off the shelf (COTS) routers with the custom OpenWRT and tailored IBR-DTN bundle protocol distribution. The on-demand service request and grant mechanisms are also developed in our implementation to allow certain DTN nodes to reserve the future access opportunities. Finally, we demonstrate the achieved capabilities and performance gains through experiments on a hardware testbed that consists of several COTS routers with our implementation.

8385-19, Session 5

Spatial telecommunications antennas behavior in presence of plasma thrusters

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The purpose of this work done was to establish the effect of the plasma exiting certain types of electric propulsions used for space explorations and telecommunications missions on an electromagnetic wave propagating inside of it and then be able to characterize the impacts that such plasma could have on spatial telecommunications antennas using

informatics programs.

The first objective of the informatics simulation is to be able to specify the different parameters interfering with the propagation of an electromagnetic wave inside the plasma plume to be able to establish conception rules for the satellite such as prohibited regions where no antennas can be installed. The plasma is characterized as a dielectric medium varying in time and space.

The second objective of the simulations is to quantify the perturbation of the plasma on the signal. All simulations characterize de effects of an SPT 100 thruster on an electromagnetic wave. This model of Hall thrusters are present on many Russian satellites and are frequently used.

The first part of the paper describes the study of plasma physics and electric propulsion systems. The second part describes the conception, development and optimization of an informatics programs which could simulate the behavior of an electromagnetic wave crossing a plasma plume. An FDTD model was also developed so as to compare results with the previous informatics program. The FDTD model enables the precise calculation of transmission, absorption and reflection due to the plasma coming out of the thruster.

8385-20, Session 5

Building a feasible software tool for analyzing RF inter-satellite links

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In this paper, software tools for analyzing the communications capabilities of Radio Frequency (RF) ISLs are developed, and validated. The software tools are extremely flexible and can be used for analyzing any free-space RF ISL. The tools explore trade-offs in the communications capability by varying the requirements, parameters, and components of the communications system. Three GUIs are developed. The first GUI can use parameters from any satellite constellation geometry to calculate the operating range of the ISLs including inter-plane ranges between satellites within the same orbit plane as well as ranges between orbital planes within satellite constellation. The second GUI can work with any type of satellite whether it is GEO or LEO and solves for an unknown parameter of the communications system when all other parameters are given. The third GUI extends the analysis capability by plotting the trade-off between two parameters over a specified range of data. These plots analysis of the trade- off parameters for ISLs can indicate the crucial parameters which have the largest effect on system design and allows smooth and efficient design for ISLs.

8385-21, Session 5

Integrated situational awareness for cyber-attack detection, analysis, and mitigation

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Real-time cyber situational awareness and proactive impact mitigation are critical for securing and protecting computer networks from various cyber threats. When a security incident occurs, network operators and security analysts need to know what exactly has happened in the network, why it happened, and what actions or countermeasures should be taken to quickly mitigate the attack's impacts. In this paper, we propose an integrated situational awareness and impact mitigation system for efficient cyber attack detection, analysis and mitigation in large-scale networks. Essentially, a comprehensive multi-layer common operating picture is developed, to efficiently represent and display the related network status, cyber security events, operational missions, and their inter-dependency relationships. Shared among authorized end-users, this operating picture can provide a common visual representation of what's going on across the network, and contribute significantly to a more efficient and effective overall response. Advanced analysis techniques, such as Bayesian network and game theory, are used to address the information uncertainty, dynamic and complex attack detection, and optimal impact mitigation. The developed technologies can be further integrated into an automatic software tool to achieve accurate, comprehensive, and near real-time cyber situational awareness and impact mitigation in large-scale computer networks.

8385-22, Session 6

On effectiveness of network sensor-based defense framework

D. Zhang, L. Ge, W. Yu, Towson Univ. (United States); G. Chen, DCM Research Resources, LLC (United States); K. Pham, Air Force Research Lab. (United States)

Networking technologies have given rise to today's worldwide social, business, and military networks, and commercial networks in the United States has been growing explosively. Because these networks are vulnerable to various types of attacks, there is an urgent need for cyber security. To address this issue, we develop a network sensor-based defense framework that unifies the both the distributed sensors (designed to efficiently process network traffic and intelligently generate network alerts), the effective anomaly detectors (to cooperatively detect attacks from the collected network alerts and detection of highly distributed attacks). We propose to deploy various open-source sensors and integrate the detection information (e.g., attack-alerts) from those network sensors with incorporation of the user to reason over the attack data. The detection information will also be integrated with the information from other sources, including the network management and system knowledge (e.g., human intelligences, subjective knowledge, environmental factors, and contextual knowledge). To minimize the detection system impact on the mission critical networks (e.g., the defense satellite communication system designed to provide high-volume and secure communication infrastructure for supporting real-time voice and data communication), we adopt the information theory and image processing techniques to efficiently process a large volume of alerts information, to identify the most informative data and alerts and provide accurate decision to the network manager. Our detection approaches can be more effective to detect attacks via using the key features of attacks (e.g., the distribution of source/ destination IP addresses and attack insights learned from Honeypot), instead of the network features, which can be easily manipulated by attacker such as traffic volume.

8385-23, Session 6

Game models in frequency hopping based proactive jamming mitigation for space communication networks

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In this paper, we represent a cognitive radio based space communication network as a game-theoretical system. Networked sensors, modeled as a set of game players, interact dynamically through wireless channels to utilize the wideband spectrum for their objectives. The objectives include performance indices of data rate, covertness, jamming and anti-jamming, and sensor signal-nose-ratio (SNR). The game players have different intents and asymmetric and hierarchical information; from which we model three different types of players: primary users, secondary users, and hostile active jammers. We consider the informational asymmetry in two situations: first, different information sets for friendly users and jammers; and second, even among friendly sensors, some sensors may only have partial or little information about others due to jammed observations. Such an asymmetric information pattern naturally partitions the sensors into leaders and followers. In our hierarchical anti-jammer approach, a non-cooperative pursuit-evasion game is constructed to model the high-level interactions between jammer and primary user in the frequency-location domains. At the lower level, primary and secondary

users play a dynamic Stackelberg game in the presence of jammers. Game solutions are provided to demonstrate the proposed proactive jamming mitigation solution.

8385-24, Session 6

Multileader Stackelberg games for anti-jamming cognitive radio

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During tactical operations, cognitive sensors continuously monitor and detect jammers via spectrum sensing and signal classification. Detected jammers will be treated as “target-leaders”, whose information is known to cooperative sensors during the observation period and will be active mitigated through gaming strategies. Non-detected jammers will be treated as “interference”, whose individual knowledge is unknown but the aggregate effects to sensors can be sensed and mitigated via properly imposed interference constraints. In anticipation of multiple active jammers, we develop a multi-leader Stackelberg game (MLSG) solution which requires new methods to characterize the sensor-to-jammer relations. The MLSG problem is challenging because it is hard to characterize the equilibriums of the dynamically interacting jamming leaders. The existence of multiple leaders obstacle has hindered existing Stackelberg games, which are only operational for the single-leader situations. In this work, a selective cognitive radio strategy for leader-follower interactions will be devised to solve the multiple-leader challenge. In the first selection step, each follower (cognitive sensor) assesses the impact of all target-leaders (jammers) and selectively locks on to one target-leader. In the ensuring second gaming step, the followers will play a single-leader Stackelberg game with the individually selected target-leaders, while treating the impact of all other target-leaders and even non-detected jammers using interference constraints constructed from the sensed aggregate interference. Such a two-step sensor-to-target strategy circumvents the technical difficulty of a direct multi-leader game, and retains the user diversity gains of multi-leader games.

8385-25, Session 6

High-fidelity, wireless-network evaluation for heterogeneous cognitive radio networks

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We present a high fidelity cognitive radio (CR) network emulation platform for wireless system tests, measurements, and validation. This versatile platform provides the configurable functionalities to control and repeat realistic physical channel effects in integrated space, air, and ground networks. We combine the advantages of scalable simulation environment with reliable hardware performance for high fidelity and repeatable evaluation of heterogeneous CR networks. This approach extends CR design only at device (software-defined-radio) or lower-level protocol (dynamic spectrum access) level to end-to-end cognitive networking, and facilitates low-cost deployment, development, and experimentation of new wireless network protocols and applications on frequency-agile programmable radios. Going beyond the channel emulator paradigm for point-to-point communications, we can support simultaneous transmissions by network-level emulation that allows realistic physical-layer interactions between diverse user classes, including secondary users, primary users, and adversarial jammers in CR networks. In particular, we can replay field tests in a lab environment with real radios perceiving and learning the dynamic environment thereby adapting for end-to-end goals over distributed spectrum coordination channels that replace the common control channel as a single point of failure. CR networks offer several dimensions of tunable actions including channel, power, rate, and route selection. The proposed network evaluation platform is fully programmable and can reliably evaluate the necessary cross-layer design solutions with configurable optimization space by leveraging the hardware experiments to represent the realistic effects of physical channel, topology, mobility, and jamming on spectrum agility, situational awareness, and network resiliency. We also provide the flexibility to scale up the test environment by introducing virtual radios and establishing seamless signal-level interactions with real radios. This holistic wireless evaluation approach supports a large-scale, heterogeneous, and dynamic CR network architecture and allows developing cross-layer network protocols under high fidelity, repeatable, and scalable wireless test scenarios suitable for heterogeneous space, air, and ground networks.

8385-26, Session 7

Negentropy-based detection of radio-frequency interference in spaceborne microwave radiometers

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Anthropogenic radio-frequency interference (RFI) negatively impacts the operation of spaceborne microwave radiometers. Since radiometers are passive radio receivers, they are subject to and impacted by the growing number of radio emissions that occur on Earth, despite the enforcement of internationally protected observation bands in which radiometers can operate without co-channel interference. Spurious emissions due to source transmitter non-linearity and violators of international frequency allocations result in an increasingly problematic observation environment for microwave radiometers. Negentropy as a detector of non-Gaussianity of a radiometer’s waveform is studied and shown to have comparable performance to kurtosis and other statistical RFI detection methods.

8385-27, Session 7

Ground emitter localization via fusing terrain map and DOA using two miniature UAS

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Real-time day/night all-weather alerting and cuing of ground emitters prevent surprise attacks to battlefield assets and enable timely countermeasures to potential terrorist activities. Current localization techniques have performance limitations such as low localization accuracy, high complexity, and large latencies. For example, in traditional direction of arrival (DOA) estimation, target elevation estimation accuracy is low due to the low elevation angle accuracy. Likewise, in multiple (three or more) unmanned aircraft systems (UAS) time difference of arrival (TDOA) fusion or frequency difference of arrival (FDOA) fusion, fine time synchronization or fine frequency synchronization among air borne receivers is needed and the communication bandwidth required for transmitting raw or baseband samples is high. With a dynamic emitter, we desire methods to reduce the latencies of TDOA or FDOA with only two UAS to localize the emitter with reasonable accuracy.

In this paper, we presents a novel ground emitter localization method, where the terrain map and direction of arrival (DOA) including azimuth and elevation angles of the emitter with respect to two small UAS (i.e., WASP-III) are fused to localize the ground emitter. Reasonable localization accuracy is achieved in real time and at low cost. In the proposed method, the two UAS are equipped with non linear smart antennas with three elements on the UAS wing tips and the UAS body head. Thus emitters in front and behind the UAS can be separated

and the smart antenna has coarse elevation DOA angle estimation capability. The DOA collected on the two UAS, the DOA time tag, the UAS position, and the signal spectrum signature corresponding to the DOA are transmitted to the UAS ground control station via the control channel. At the ground station, the DOA is aligned using time tag and spectrum signature. The aligned azimuth angles are fused to estimate a set of emitter horizontal position. And then the emitter DOA elevations corresponding to the horizontal positions are estimated using the terrain map. The elevation and azimuth angles of the estimated emitter position with respect to the two UAS are calculated. The position with the smallest difference between the estimated DOA and the calculated DOA is taken as the emitter position.

The proposed technique using two small UAS can also be applied to multiple small / larger UAS for increased performance. In the analytical model with two UAS, the proposed technique can localize emitter within 100 meters in an area with radius of 2000 meters.

8385-28, Session 8

On the robustness of a new sparse data association technique for low-earth-orbit object tracking

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This paper deals with the association problem of sparse data (isolated reports) provided by a ground-based radar system for space surveillance, to which too few efficient approaches have been proposed at this time [1] [2]. The method we propose and investigate aims at correlating sets of isolated reports originated from successive orbit revolutions. Resulting tracks should contain enough information to deduce sufficient initial guesswork for the initial orbit determination step (IOD, [3]).

The hypothesis of a single ground-based radar installation of wide cross-elevation (160°), narrow elevation (2°) field-of-regard providing 3D measurements is made. As realistic input data, the Two-Lines Elements (TLE) space objects catalogue provided by Space-Track is used. The aim is to be able to correctly associate detections from one pass to another after one orbit revolution without testing all the possible combinations between the detections and false alarms. The information extracted from a simulation using a SGP4 propagator [5] enables to deduce the distributions of the spotted-objects altitudes relating to well-chosen dynamic parameters. For each new set of isolated reports, a probability density of the reappearance period given the mean altitude of detection is retrieved. The orbital states being unavailable due to too few information contained in each set, metric distances are introduced and used jointly with a time window for the gating, which contributes significantly to reducing the number of association hypothesis. Besides, probability densities associated to such gates are computed, enabling the attribution of first-association scores.

The principle, functioning and performance of the method on realistic simulation are presented, as well as leads of improvement for future works.

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8385-30, Session 8

GEOScan: a geoscience facility from space

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Geoscience and operational space situational awareness is at the dawn of a new era, and the past decade has seen a confluence of events supporting this statement. Many geoscientists believe that future discovery and understanding of our Earth environment requires taking a view of the Earth-atmosphere-geospace as a complete system. Motivated by this revelation is the growing view that as researchers we cannot tackle many open questions without global coverage of key measurements. Fortunately, many measurements of interest support the deployment of global and dense arrays of instrumentation on both the ground and space based platforms. Due to technological advancements in commercial of the shelf (COTS) instrumentation these global measurements are now achievable at a fraction of the historic cost. This cost reduction results from using commercially developed instruments that are repurposed from their original consumer and industrial uses, such as GPS, inertial measurement, and magnetometers, and new low cost access to space via commercially available hosted payloads, sub-orbital flights, and cube-sats CubeSats. We will present recent research on this topic in general, and focus specifically on expected science and operationalcapabilities of GEOScan, an initiative to place instruments on the Iridium NEXT constellation of satellites.

8385-31, Session 8

Overview of the Sapphire payload for space situational awareness

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This paper provides an overview of the satellite based Sapphire Payload developed by COM DEV to be used for observing Resident Space Objects (RSOs) from LEO by the Canadian Department of National Defence. The data from this operational mission will be provided to the US Space Surveillance Network as an international contribution to assist with RSO precision positional determination.

The payload consists of two modules; an all reflective visible-band telescope housed with a low noise preamplifier/focal plane, and an electronics module that contains primary and redundant electronics.

The telescope forms a low distortion image on two CCDs adjacent to each other in the focal plane, creating a primary image and a redundant image that are offset spatially. This combination of high-efficiency low-noise CCDs with well-proven high-throughput optics provides a very sensitive system with low risk and cost.

Stray light is well controlled to allow for observations of very faint objects within the vicinity of the bright Earth limb. Thermally induced aberrations are minimized through the use of an all aluminum construction and the strategic use of thermal coatings.

The payload will acquire a series of images for each target and perform onboard processing of the images to minimize the downlink requirements. Internal calibration sources will be used periodically to check for health of the payload and to identify, and possibly correct, any pixels with low response.

This paper also provides a summary of the testing that was performed and the results achieved.

8385-32, Session 8

Earth impactors: threat analysis and multistage intervention mission architecture

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Earth Impactors (EI) pose a significant threat ranging from worldwide to local devastation. This threat has prompted congress to instruct NASA to identify 90% of near earth objects (NEOs) larger than 140 meters by 2020 [1]. Upon EI detection, a response mission is required to modify the EI's orbit to prevent impact or to fragment and disperse the EI (reducing impact damage severity). The EI response architecture is a multi-stage approach suitable for responding to 75% of solar orbit NEO EIs, based on analysis of the projected NEO EI population compiled by Veres, et. al. [2].

This architecture defines two timeframes: rapid response (RRTA) for objects detected on final approach and extended response (ERTA) for objects detected years before impact. Both begin with a reconnaissance mission. The RRTA's reconnaissance mission and intervener are launched in close succession; intervention involves deploying a tactical nuclear charge to alter the course of or break apart the EI. The extended (ERTA) response, conversely, allows analysis of collected physical characteristic data such as the approximate mass, composition and mass distribution before intervener launch. Intervention may involve redirecting the EI away from Earth by applying limited thrust over an extended time period.

The reconnaissance mission, under both scenarios, will be conducted by a small spacecraft equipped with a suite of payload instruments that include a radio science package, visual camera, multi-spectral imager, LIDAR and, optionally, a radar tomography sensor. Sensor tasking and control for this mission will be autonomous based on controller-supplied objectives.

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8385-33, Session 8

Short arc gating in multiple hypothesis tracking for space surveillance

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Space surveillance is concerned with keeping track of all man-made objects orbiting the Earth.

Objects at high altitudes are mostly observed by ground-based optical sensors that produce only a very short arc observation from which only the angles and angular rates can be determined.

Multiple Hypothesis Tracking (MHT) methods are under development for persistent space surveillance and one challenging problem is the accurate and timely orbit initiation from sets of uncorrelated observations.

In particular given optical observations, several observations need to be correlated before accurate track initiation can be performed.

As the number of initiation hypotheses grows exponentially with the number of observations, gating, designed to rule out infeasible correlations, is crucial in an MHT.

This paper develops gating methods for correlation of optical observations in space surveillance.

A pair gate based on the concept of an admissible region is introduced.

Different gate score functions are evaluated, including a score based on Bhattacharyya distance and a computationally cheap score based on Mahalanobis distance.

By implementing a hierarchy from fast, but coarse, to more expensive but accurate (fine) gates the number of hypotheses to be considered for initial orbit determination is reduced considerably.

Simulation results demonstrate the effectiveness of the gating procedure in removing infeasible correlations and address gate parameter determination from Receiver-Operating Curve characteristics.

Furthermore we study the accuracy of initial orbits determined by the gate function and present run-time estimates to support feasibility of the proposed gating scheme towards real-time MHT for space surveillance.

8385-29, Poster Session

Management of radar resources for space debris tracking

M. Mendijur, P. Besso, M. Sciotti, European Space Operations Ctr. (Germany)

Radar sensors, devoted to Space Situational Awareness (SSA), support the identification of close conjunctions between space debris (or other spacecrafts) and valuable space assets. Ground-based radar data allow refreshing and maintaining the orbital parameters for the catalogued objects in Low Earth Orbit (LEO) regimes. The availability of accurate and up-to-date orbital data is fundamental for achieving a good probability of early detecting a potential collision with low false alarm rate. However, the multitude of required observations (tens of thousands of debris expected in 2040 in the same LEO regimes of most civilian satellites) and the scarceness of SSA-devoted sensors lead to complex optimization issues.

In the frame of the European Space Agency SSA Preliminary Programme, the design for a ground-based phased array radar - aimed at LEO surveillance - has been proposed. A fence-shaped volume of the sky is routinely, electronically scanned by the radar beams in order to feed the Track-while-Scan (TwS) processor - an L-band radar breadboard is currently under development following this approach. The actuation of Active Tracking (AT) tasks is also considered, in parallel with the use of dedicated tracking radars for orbit refinement. The optimal strategy for managing the TwS/AT resources of the phased array radar is hereafter derived from the accuracy requirements dictated by the collision warning services. Resource savings is addressed in terms of observation time for target acquisition, track confirmation and track refinement. Simulation results over a representative debris population dataset are presented in order to support the analysis.

8385-34, Poster Session

Mechanisms for space applications

M. Meftah, Ctr. National de la Recherche Scientifique (France)

All space instruments contain mechanisms or moving mechanical assemblies that must move (sliding, rolling, rotating, or spinning) and their successful operation is usually mission-critical. Generally, mechanisms are not redundant and therefore represent potential single point failure modes. Several space missions have suffered anomalies or failures due to problems in applying space mechanisms technology. Mechanisms require a specific qualification through a dedicated test campaign.

This paper covers the design, development, testing, production and in-flight experience of the PICARD/SODISM mechanisms. PICARD is a space mission dedicated to the study of the Sun. The PICARD Satellite was successfully launched, on June 15, 2010 on a DNEPR launcher from Dombarovskiy Cosmodrome, near Yasny (Russia). SODISM (SOlar Diameter Imager and Surface Mapper) is a 11 cm Ritchey-Chretien imaging telescope, taking solar images at five wavelengths. SODISM uses several mobile mechanisms (a system to unlock the door at the entrance of the instrument, a system to open/closed the door using a stepper motor, two filters wheels using a stepper motor and a mechanical shutter). For the fine pointing, SODISM uses three piezoelectric devices acting on the primary mirror of the telescope. The success of the mission depends on the robustness of the mechanisms used and their life.

8385-35, Poster Session

Space object, high-resolution, optical imaging simulation of space-based systems

H. Zhang, Beihang Univ. (China); W. Zhang, Z. Jiang, BeiHang Univ. (China)

Acquiring optical images of space objects is one of the most important goals of space-based space surveillance systems. However, it's actually difficult to obtain enough high resolution optical images for space object recognition, attitude measurement and situational awareness. Image simulation is an effective way to solve this problem. In this paper, a novel method of image simulation is proposed, which is based on the analysis of the imaging model of space-based optical camera and the imaging characteristics of space objects. The relative position among the sun, the earth, the camera and the object is considered together with the shape, structure, and reflective properties of materials of the space object. In our procedure for simulating space object optical images, we firstly create a three-dimensional model of the object, which contains geometric details and reflection parameters of the materials on different parts of the object, and import the model into a 3ds max scene. Then, within the 3ds max scene, we use video camera to simulate visible camera, set parallel light to simulate sunlight, and render this scene to generate ideal images of the object from different distances and different viewpoints. Finally, to improve the reality of simulated images, a point-spread function filter is applied to the ideal images, and motion blur and noise are also added via another two filters. The high resolution images of space objects simulated by our method are visually similar to the actual imaging results and may provide data support for further research on space technology.

8385-37, Poster Session

Precise altitude measurements of LEO objects with simultaneous observations by multiple telescopes

H. R. Schmitt, Computational Physics, Inc. (United States); R. B. Hindsley, J. T. Armstrong, E. K. Baines, U.S. Naval Research Lab. (United States)

The increase in the number of satellites and space debris in low Earth orbit (LEO) makes tracking these objects and avoiding collisions a major endeavor. A particularly important issue is the determination of the altitude of these objects, which in many cases is not known to a precision better than ~1 km. Here we present the idea of using simultaneous observations by optical telescopes separated by a few hundred km, to refine the altitude measurement of these objects to a precision of ~10 m. We will discuss the requirements for such a system, such as aperture, detector area, and timing precision, as well as the precision to which one needs to know the positions of background stars. We will also discuss the case in which one does simultaneous observations from a small telescope located in Kauai with the Pan-STARRS telescope in Maui, which should allow the measurement of the altitudes of a large number of objects on a single night.

8385-38, Poster Session

Design and analysis of a space-based imaging spectrometer

P. C. Hill, P. L. Thompson, B. McAndrew, G. G. Gochar, NASA Goddard Space Flight Ctr. (United States); J. Guzek, Design Interface, Inc. (United States)

As part of the CLARREO mission, the SOLARIS instrument project at Goddard Space Flight Center has designed and built an all aluminum imaging spectrometer. The instrument is a science demonstration unit that will be used to evaluate the feasibility of achieving the 0.3% radiometric measurement accuracies required for the CLARREO mission. The instrument design is a Three Mirror Anastigmat (TMA) with an Offner spectrometer that operates from 320 nm to 2.3 um. This paper will present the design philosophy and the design trades used to optimize the final design of the demonstration unit.

Presently, an integrated optical model is being developed to include the as manufactured performance of each optical component. A high fidelity optical model is needed for both integration and test of the instrument as well as for instrument calibration. This paper will present the measurement methodology and manufactured performance of each optical component. Moreover, the paper will discuss the opto-mechanical alignment sensitivities of the design and will present an alignment approach for optimizing the final performance of the instrument. Concluding will be a comparison between the performance of the assembled instrument and the optical model.

Conference 8386: Full Motion Video (FMV) Workflows and Technologies for Intelligence, Surveillance, and Reconnaissance (ISR) and Situational Awareness

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8386-01, Session 1

Successes and challenges of merging motion imagery into intelligence analysis

G. Young, National Geospatial-Intelligence Agency (United States)

Meeting the challenges of the war on terrorism has resulted in the increased demand of airborne imagery to include an explosion of airborne video sensors. The resulting increase of airborne sensing data has been a boon for analysts. Analyst's increased understanding and discovery of actions and intentions of our adversaries has led to the defeat of huge number of adversary operations. The integration of large amounts of this relatively new sensor data has not been without significant challenges. The presenter will discuss the methods and tradecraft for the integration of airborne motion imagery data into a multi-intelligence analysis and production environment. This discussion will include problems and issues associated with bringing multiple sources and data types onto the analyst's desktop in a timely and efficient manner. Change management has not been trivial. The presenter will provide the unique perspective of the challenges of changing the imagery intelligence analyst mindsets and tradecraft to fuse motion imagery into the predominantly still-imagery realm that is still prevalent today. Additionally, a discussion of the maturing field of forensic analysis and how motion imagery aids in this type of analysis will also be covered.

8386-02, Session 1

Transformational motion imagery processing, exploitation, and dissemination (PED) technologies

G. Creech, M. Brennan, National Geospatial-Intelligence Agency (United States)

Increases in size and volume of data from tactical ISR platforms and the resulting burden placed on limited Department of Defense (DoD) and Intelligence Community (IC) analytic resources is a problem area that will only get worse with time - unless the community does something to intervene. Intervention on an enterprise scale requires reexamination and retooling of the entire PED chain, which supports both forward deployed and reachback support analysts. This paper examines current community research and NGA efforts to leverage and integrate the most promising technologies to enhance usability of motion imagery to support GEOINT production and analysis. Beginning with a snapshot of "where we are now," the paper will describe capability gaps and potential technology insertion points and milestones to achieve a near term (within 2-3 years) desired end state. The enhancement efforts cover PED chains for both wide area and narrow field of view sensors, with strong emphasis on workflow and process automation. While automation is key and critical to slowing down the spiraling problem of data overload, it is recognized that all intelligence problems are not "machine solvable" and therefore a delicate balance between human and machine must be designed and maintained, in order to meet critical timelines, achieve desired throughput, and get the most intelligence value out of the massive amounts of data collected. NGA, InnoVision's Advanced PED (APED) Branch continues to seek innovative ways to package and deliver enhanced analytic capability to the warfighter and envisions new capability falling into one of three areas: 1) enhances an existing PED chain ; 2) part of a newly-conceived PED chain; or 3) stands alone as either a pre or post-PED enhancement.

8386-03, Session 1

Convergence in full motion video processing, exploitation, and dissemination and activity based intelligence

M. Phipps, G. Lewis, General Dynamics Advanced Information Systems (United States)

Over the last decade, intelligence capabilities within the DoD/IC have evolved from ad hoc, single source, just-in-time, analog processing; to multi source, digitally integrated, real-time analytics; to multi-INT, fused, predictive Processing, Exploitation, and Dissemination (PED). Full Motion Video (FMV) technology and motion imagery tradecraft advancements have greatly contributed to Intelligence, Surveillance, and Reconnaissance (ISR) capabilities during this timeframe. Imagery analysts have exploited events, missions, and high value targets, generating and disseminating critical intelligence reports within seconds of occurrence across operationally significant PED cells. Now, we go beyond FMV, enabling All-Source Analysts to effectively deliver ISR information in a multi-INT sensor rich environment. In this paper, we explore the operational benefits and technical challenges of an Activity Based Intelligence (ABI) approach to FMV PED. Existing and emerging ABI features within FMV PED frameworks are discussed: refined motion imagery tools, additional intelligence sources, activity relevant content management techniques, and automated analytics.

Specifically, refined FMV PED reporting and collaboration techniques are highlighted from both a PED cell and enterprise framework perspective. We also look at leveraging persistent surveillance data for context and incorporating tipping and cueing mechanisms into the PED workflow. Data filtering and organization options and automated and user-assisted object detection and tracking are essential to enabling the analyst to focus on the exploitation challenges that now exist. Novel analytical methods and tools must be integrated into the current PED workflow as well, enabling analysts to further investigate the relationships between the exploited data and the real world activity being observed.

8386-04, Session 2

Improving usability for video analysis using gaze-based interaction

J. Hild, E. Peinsipp-Byma, E. Klaus, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Video analysts face a demanding task. There are periods of high workload, for example when monitoring several video streams at the same time or when trying to select fast moving objects in a video stream. Furthermore, there are phases that cause fatigue or low attention, for example when over a long time no noticeable event occurs. In this contribution, we suggest different methods to support the video analyst using eye tracking technology differing between explicit and implicit use of gaze information.

Explicit use of eye tracking means that the user is aware of using gaze for interaction. Most commonly, gaze is used to substitute mouse pointing to simplify interaction and in consequence to reduce workload. Based on this kind of interaction, we implemented two new interaction techniques for video analysis: gaze-based selection of a video of interest from a set of video streams and gaze-based selection of moving objects in videos. First results show that the gaze+key interaction allows the selection of fast moving objects in the full motion video in a more effective way . Implicit use of eye tracking means that the user is not aware that his gaze is used to support interaction. Different applications using eye tracking in

an implicit mode seem to be of interest for video analysis: Gaze behavior is already used to measure the fatigue of truck drivers. It seems obvious to apply this function for video analysts, too. Another application is to analyze the gaze behavior of expert analysts to instruct beginners.

8386-05, Session 2

Georegistration of motion imagery with error propagation

M. D. Pritt, Lockheed Martin Information Systems & Global Services (United States); K. J. LaTourette, Lockheed Martin Tactical Defense Systems (United States)

Georegistration is the assignment of geospatial coordinates to the pixels of an image. It is necessary for many activity-based intelligence tasks. Motion imagery is difficult to georegister, because the sensor/camera models--that is, the mathematical mappings from world to image coordinates--are not known accurately enough in practice, even when platform GPS data are available. Terrain elevations, parallax from tall buildings and trees, and wide sensor fields of view complicate the problem even further. We have developed a fully automated and accurate solution to the georegistration problem that runs in real time on a PC. It works for practically any image type, whether still or motion, aerial or satellite, and optical or radar. It is based on the formation of predicted images from digital elevation models (DEMs) followed by registration to actual images. Our system can handle difficult cases where features in the DEM differ significantly from those in the image, such as a bare-earth DEM that lacks buildings and tree canopy structure, or a DEM with coarse post spacing that differs from the image resolution. We will present results on a variety of aerial motion imagery, including full motion video and multi-camera WAMI. We will also present rigorous photogrammetric error propagation results to estimate its accuracy and compare with ground truth GPS.

8386-06, Session 2

Full-motion video georegistration for accuracy improvement, accuracy assessment, and robustness

C. R. Taylor, F. Bandukwala, R. J. Settergren, BAE Systems (United States)

Emerging standards for video metadata provide the means, in principle, for accurate geopositioning from full motion video. Georegistration to reference data as part of the workflow adds value by improving the metadata accuracy, establishing a check against mismodeling in the metadata and the corresponding a priori error covariance, and providing a mechanism to recover usable geopositioning capability in the event of failure of the system generating or transmitting the metadata. Georegistration may be done on board the collecting platform, at a ground station, or at any point in the exploitation process. A system capable of full motion video georegistration to reference data will be described, which establishes a photogrammetrically rigorous sensor model for each video frame. The sensor model operating parameters and error covariance are updated based on matches between pairs of frames and between frames and reference data. The challenge of finding associations between the reference data and the video images taken under very different imaging conditions is met by using both direct and feature matching approaches. Methodology for the validation of georegistration will be presented. Test results will be given for an operational real-time video georegistration system.

8386-07, Session 2

Dealing with the data deluge: file systems and storage technologies

K. Kern, NetApp U.S. Public Sector (United States)

As defense and intelligence agencies seek to use the increasing amount of available data to make mission critical decisions on the battlefield, there is heavy emphasis on smart data and imagery collection, capture, storage and analysis to drive real time intelligence. This reality leads to an inevitable challenge - warfighters are increasingly swimming in sensors, drowning in data. With the millions, if not billions, of sensors in place that provide all-seeing reports of the combat environment, managing and tackling the overload is critical. This session highlights the capabilities of file systems and storage technologies that can interactively manage 100M+ files and 1PB+ single directory file system.

A single hour of data collection can result in more than 7 million files from just one camera. Collection opportunities are limited and must be 100% successful every time. Management of this data requires a file system and storage infrastructure that scales and performs while protecting the collected data. Once the data is collected the file system must support rapid interaction with not only the data, but the file system organizing and serving the data. This paper discusses file systems and storage technologies which can interactively manage 100M+ files and 1PB+ single directory file system.

Option to attack this:

-Cache optimized for MetaData acceleration - FlashCache

-Integrated file system - OnTap 8.1

-Clustered storage systems - OnTap8.1 cluster mode

-Reliability - Raid DP

-StorageGrid

-StorNext

-Scalability - E-Series or FAS6x00

8386-08, Session 3

Motion/imagery secure cloud enterprise architecture analysis

J. L. DeLay, Harris Corp. (United States)

In the media and entertainment industry there is a widely used phrase that “content is king” and this is equally true of data collected by the intelligence community. Motion Imagery and Imagery Content equal intelligence-a FMV clip from a Predator, a Persistent Surveillance data collect, open source news feeds, imagery etc. An intelligence value may be attached to that content by an analyst and ultimately many consumers may enhance the original content with additional context which increases the contents original intelligence value. In essence content is information and in a world of information technology, content needs to be analyzed and manipulated as information.

All content should be considered an asset, but in today’s digital media environment its true value will only be realized if you have extremely precise geo-spatial, temporal and contextual metadata, up-to-the-second knowledge of what assets you have, where it all is, who needs it, when it needs to be delivered, what form is required and finally that it has arrived to its respective users. All of this information about your content needs to be discoverable across the enterprise at any time from a single view. Media and Entertainment organizations like intelligence organizations have traditionally kept their content in their local facilities. But with file-based media asset management workflows and cloud technologies building a high-performance; highly scalable media asset management content repository where users have instant access to motion imagery and imagery regardless of the volume, location or format of the content.

8386-09, Session 3

Transitioning ISR architecture into the cloud

T. Lash, SAIC (United States)

This presentation addresses unique aspects of both ISR and Cloud Architectures and discusses implementation details for a successful transition. We examine best practices and industry trends from consumer Cloud implementations of ISR-like functionality, review common ISR CONOPS to develop an idealized ISR Architecture in the Cloud, and then address specific deployment steps. Finally, we examine the benefits to stakeholders of successfully transitioning ISR architecture to the Cloud.

8386-10, Session 3

NGA/JITC GEOINT repository provides centralized and formalized source of community test data

R. L. Richard, Joint Interoperability Test Command (United States)

As a centralized, formalized, data repository, the GEOINT Repository is an answer to the largely disparate, often difficult to obtain, sources of GEOINT test data. It is housed at the Joint Interoperability Test Command (JITC), leveraging their close relationship with collocated GEOINT Laboratories, namely the Motion Imagery Standards Laboratory (MIS-LAB) and the National Imagery Transmission Format Standards Laboratory (NITFS) that operate at JITC. The GEOINT Repository is designed to provide the DoD GEOINT community (US Only initially, expanding to Coalition) sets of test data normally provided by the MIS-LAB, NITFS Lab, and other non- test-centric sources. Data immediately available to the community are listed and described in the GEOINT Repository test data catalog, accessible on both NIPRNet and SIPRNet using the Repository's respective sites. Rough assessments are performed on each file processed and analysis data are provided to the customer. In addition, data are graded according to standards compliance based on what elements of the data effect compliance. Current grading is at the Gold, Bronze, and Tin levels. Test data that are available but not graded are operational, synthesized, and customized data. Customers who cannot find what they need in the catalog have the option of making "special orders," which the GEOINT Repository staff researches for sourcing and fulfillment. Also, customers can order customized data, data modified to meet their specialized needs. It is a one stop shop for DoD GEOINT customers needing data to test their systems. The GEOINT Repository website can be found at http://jitc.fhu.disa/cgi/geo/ (NIPRNet).

8386-11, Session 4

Activity-based intelligence: concept, challenges, and way ahead

M. Choiniere, National Geospatial-Intelligence Agency (United States)

Activity-Based Intelligence (ABI) is an evolving strategy for developing intelligence using the combined capabilities of persistent surveillance, tailored collection management, multi-INT analytic tradecraft and flexible and discoverable data management. It is a discipline of intelligence where the analysis and subsequent collection is focused on the activity and transactions associated within an area of interest. The concept of ABI is not new. Analysts extract relevant pieces of information and intelligence from a pool of data relevant to their area to interest to discern activity and transactions. What has changed is the increasing sensing capability coupled with the emergence of automation technologies to extract a greater amount of relevant data. ABI drives changes to analytical tradecraft. ABI enables analysts to collect, characterize and locate activities and transactions; identify and locate actors conducting the activities and transactions; identify and locate networks of these actors; understand the relationships between networks; and develop patterns of life. Activity-Based GEOINT focuses on capturing activities as they occur and, based on understanding of patterns of life, analyzing those activities to determine normal from abnormal, to determine relationships, to discover networks, and to project and forecast in support of anticipatory intelligence analysis. This presentation discusses the NGA goal is to automate, improve and expand the people skills, analytic processes and enabling technologies (e.g., processing, etc) to get faster, more relevant and accurate GEOINT and MULTI-INT and to do so in "activity" terms, outcomes and information.

8386-12, Session 4

Activity-based exploitation of full motion video

S. Kant, Cognika Intelligence & Defense Solutions, LLC (United States)

Video has been a game changer in how our US forces are able to find and track its adversaries. With millions of minutes of video being generated from an increasing number of sensor platforms, the DOD has stated that the rapid increase in video is overwhelming their analysts. The manpower required to view and garner useable information from the flood of video is unaffordable, especially in light of current fiscal restraints. "Search" within full-motion video has traditionally relied on human tagging and associated metadata to provision filtering and locate segments of interest, in the context of analyst query. Our approach utilizes a novel machine-vision based approach to index FMV, using object recognition & tracking, events and activities detection. This approach enables FMV exploitation in real-time, as well as a forensic look-back within archives. This approach can help get the most information out of video sensor collection, help focus the attention of overburdened analysts, help form connections in activity over time and conserve national fiscal resources in exploiting sensor video.

8386-13, Session 4

Automated motion imagery exploitation for surveillance and reconnaissance

S. Se, F. Laliberte, V. Kotamraju, M. Dutkiewicz, MacDonald, Dettwiler and Associates Ltd. (Canada)

Airborne surveillance and reconnaissance are essential for successful military missions. Such capabilities are critical for troop protection, situational awareness, mission planning and others. Both manned and unmanned airborne platforms gather huge amounts of video data, but it is extremely labour-intensive for operators to analyse hours of collected data.

At MDA, we have previously developed a suite of automated video exploitation tools that can process airborne video, including mosaicking, change detection and 3D reconstruction, within a GIS framework. The mosaicking tool produces a geo-referenced 2D map from the sequence of video frames. The change detection tool identifies differences between two repeat-pass videos taken of the same terrain. The 3D reconstruction tool creates calibrated geo-referenced photo-realistic 3D models.

The key objectives of the on-going project are to improve the robustness, accuracy and speed of these tools, and make them more user-friendly to operational users. Robustness and accuracy are essential to provide actionable intelligence, surveillance and reconnaissance information. We are porting some processor-intensive algorithms to run on a Graphics Processing Unit (GPU) in order to improve throughput. Many aspects of video processing are highly parallel and well-suited for optimization on GPUs, which are now commonly available on computers.

Moreover, we are extending the tools to handle video data from various airborne platforms and developing the interface to the Coalition Shared Database (CSD). The CSD server enables the dissemination and storage of data from different sensors among NATO countries. The CSD interface allows operational users to search and retrieve relevant video data for exploitation.

8386-14, Session 4

Unsupervised visual landmark extraction for place recognition

E. Sariyanidi, H. Temeltas, Istanbul Teknik Üniv. (Turkey)

Place recognition is a very active research subject which has been researched by many authors. Using visual sensory to achieve place recognition has become very popular in the last decade, thanks to the improvements in computer processors and many novel image analysis algorithms proposed by the computer vision community. In this paper, we propose a novel saliency detection technique which has been used for unsupervised visual landmark extraction. We formulate the saliency detection problem as an optimization problem, where we define an energy function and use a Branch&Bound based optimization technique to efficiently find the global minimum of this function. We define an upper bound for the Branch&Bound based search method to discard unpromising regions and extract the landmarks efficiently. We also benefit from integral images to furthermore improve the efficiency of the proposed technique.

We use a visual vocabulary which consists of visual words along with their empirical appearance probabilities. The appearance probabilitiy of the visual words which are extracted from incoming images, are used as the parameters of the energy function.

The output of the proposed method has been illustrated on several datasets and images. This method is also suitable for loop closure detection applications, since it runs near real-time on a standard desktop computer.

8386-15, Session 4

Placement of full-motion video frames in geographic context using pursuer

C. N. Taylor, D. Uppenkamp, K. Shannon, Air Force Research Lab. (United States)

Several technology trends have recently converged to provide the ability to view live video about an area of interest at significantly reduced cost, including the introduction of unmanned aerial vehicles, the availability of long-range digital communications, and the widespread availability of low-cost, light-weight video cameras.

While video contains a significant amount of useful information for the end-user, understanding the “context” of a video is often as important as the information within the video itself. For example, if gunfire is observed in a video, that information is only useful if the end-user observing the video can also determine where the gunfire is occuring. Similarly, if two objects of interest are observed within a video, the distance and orientation between those objects may be as important as actually observing the objects.

To provide context to video being collected about an area, we have developed a system for placing frames from a full-motion video stream in a geographic context. As a visualization platform, we utilize Pursuer, a US Air Force “government-off-the-shelf” system based on NASA’s Worldwind program. Pursuer provides an intuitive interface to see several pre-existing maps and reference imagery, all placed within geographical context (similar to Google Earth). The focus of this paper is the technology developed to add another layer to Pursuer for visualizing frames from full motion video in the same geographical context. The result of this system is that every pixel observed by the end-user has a associated GPS coordinate, implicitly answering the context questions of location, distance, and orientation.

8386-16, Session 5

Automated FMV SMART camera using dynamically updated LUTs

H. M. Jaenisch, J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We present a method for segmenting FMV video streams to dynamically extract scene recognition and change detection information using simple on-the-fly statistics. We show how the video scene can be segmented enabling sub-frame statistical characterization. The features are written into dynamic Look up Tables (LUTs) in real-time. Behavior recognition occurs by testing if the newly observed scene statistics have already been recorded in the table. The features in the LUT can later be used to derive predictive behavior Data Models. We demonstrate results of our approach on various types of FMV and micro UAV video data streams.

8386-17, Session 5

Real-time anomaly detection in full-motion video

G. Konowicz, J. Li, Old Dominion Univ. (United States)

Improvement in sensor technology such as charge-coupled devices (CCD) as well as constant incremental improvements in storage space has enabled the recording and storage of video more prevalent and lower cost then ever before. However, the improvements in the ability to capture and store a wide array of video have required additional manpower to translate these raw data sources into useful information. We propose an algorithm for automatically detecting anomalous movement patterns within full motion video thus reducing the amount of human intervention required to make use of these new data sources. The proposed algorithm tracks all of the objects within a video sequence and attempts to cluster each object’s trajectory into a database of existing trajectories. Objects are tracked by first differentiating them from a Gaussian background model and then tracked over subsequent frames based on a combination of size and color. Once an object is tracked over several frames, its trajectory is calculated and compared with other trajectories earlier in the video sequence. Anomalous trajectories are differentiated by their failure to cluster with other well known movement patterns. Adding the proposed algorithm to an existing surveillance system could increase the likelihood of identifying an anomaly and allow for more efficient collection of intelligence data. Additionally, by operating in real-time, our algorithm allows for the reallocation of sensing equipment to those areas most likely to contain movement that is valuable for situational awareness.

8386-18, Session 5

Emerging standards suite for wide-area ISR

P. Maenner, NGA Motion Imagery Standards Board (United States)

The last decade has seen the emergence of Wide Area ISR systems such as Gorgon Stare and ARGUS. These systems provide the ability to cover areas of multiple square kilometers while retaining resolution sufficient for the tracking of persons. This ability is achieved through sheer scale in terms of number of pixels; Wide Area ISR sensor systems have many times the pixel count of a standard definition or even high definition FMV sensor. Besides the well known effect of data overload, the scale of Wide Area systems has exposed a need for scale sensitive standards. The standards pertaining to SD and HD FMV sensors are useful but no longer sufficient for the needs of Wide Area systems.

We will present a survey of the current state of Wide Area system standards in the areas of data / file format, archive query interface, streaming, live sensor control, moving target indicator, metadata, and others. We will present both areas of standardization success and areas for further improvement. Current Wide Area systems often resort to adhock engineering solutions in the absence of a full suite of standards. The National Geospatial-Intelligence Agency's Motion Imagery Standards Board is cognizant of the importance of Wide Area system standards in the interest of the cost savings enabled by broad interoperability.

8386-19, Session 5

Increased ISR operator capability utilizing a centralized 360º full-motion video display

K. Andryc, T. Eagleson, P. Kuzdeba, M. Rose, G. Gottschalk, J. Chamberlain, D. LaValley, B. Kowal, N. Beluzo, B. Rusiecki, S. Quinn, E. Myers, Kollmorgen Electro-Optical (United States)

Complex battlespace environments necessitate multi-sensor systems for real-time data analysis and decision making in areas of intelligence reconnaissance and surveillance (ISR). As the number of sensors and the volume of data increases, the need to assimilate data effectively becomes increasingly difficult. This paper discusses an approach in contextualizing disparate multi-sensor data onto a full motion real-time 360º imaging display. The architecture described allows for processing and control of multiple sensor systems including remote weapon systems, automated sniper detection systems, and auxiliary electro-optical systems. The integration of sensor systems allows for increased capability, such as slewing a remote weapon station to a position identified by the sniper detection system. The scene data presented to the user is then augmented on the 360º display allowing for intuitive positional context of the sensory data. The 360º full motion video is therefore the background display for the other user data. The system described herein is comprised of a multi-camera modular sensor unit, a video processing unit, and a display unit. The sensor unit contains high-definition color cameras and standard definition long wave infrared cameras in a modular rugged enclosure allowing for multiple mission configurable designs. The video processing unit is designed around a modular FPGA architecture that is capable of processing multiple streams of sensor data in real-time. The graphical user interface (GUI) displays the 360º real-time full motion video with contextualized sensory data overlaid.

8386-23, Session 7

Wireless video technologies and standards in the broadcast and surveillance industries: a brief history

J. Roy, VISLINK Law Enforcement & Public Safety (United States)

Wireless video transmission is one of the most challenging aspects of full motion video content collection. There have been many advances in the digitization of video in the last 10 years that have allowed us to transmit that information more efficiently. Most recently the advances in the commercial/broadcast television industry have set the standards for digital wireless video transmission. An exploration of the requirements in that industry and its historic upcoming can help shape how the technologies for wireless video transmission in the surveillance industry are developed now. Much of the technology today is based off of miniaturization of broadcast wireless equipment. The transition from analog to digital transmission of video has allowed for many different standards to arise. The wireless transmission of video is a complex system that can utilize different technologies to coexist while accomplishing the same task. Best practices for the broadcast television industry have been fleshed out but to date have not been adequately adapted for the ISR activities and in particular video distribution to COTS type edge devices. A cohesive system that allows for maximum quality of service and uptime with an adaptable end user ease of use model will be proposed for most common ISR requirements. Due to the complexity of wireless video transmission, every use case needs to be evaluated before deployment. We believe that there needs to be standardization of technologies and in particular in the dissemination, i.e. last mile, for wireless video. This paper will propose model systems that that allow that to get done.

8386-24, Session 7

Salience-based compression: providing FMV over low-bit rate channels

M. Isnardi, SRI International Sarnoff (United States)

Transmitting motion imagery over low bit rate channels generally requires a tradeoff between quality, image size and frame rate. If high frame rate (FMV) and full image size are also requirements, then low quality over the entire image is the result. Although next-generation video compression standards that promise a factor of two drop in bit rate will certainly help, their actual deployment is years away. Rather than wait for new compression standards, we discuss a novel way of pre-conditioning a video signal that lowers the bit rate by up to a factor of four, yet still provides FMV and preserves salient visual information that allows actionable decisions to be made in an ISR environment. Furthermore, the pre-conditioned video signal is interoperable with today's video codecs.

SRI's pre-conditioning technology, coupled with standards-based video compression, is called Salience-Based Compression. SBC works by tracking salient features (e.g., moving vehicles) and keeping them sharp; non-salient features (e.g., large background regions) are spatially lowpass filtered, causing attenuation of high spatial frequencies and a drop in required bit rate. Because salience-based pre-filtering is performed as a pre-processing step, it can interface to any COTS video encoder, thus ensuring the compliance of the video bitstream that is produced.

SRI has developed software- and hardware-based systems that perform SBC on aerial surveillance video. Without SBC, the video format (640x480 / 30 fps) would require about 1.6 Mbps to transmit air-to-ground. With SBC, video with the same format requires on the order of 400 kbps to send air-to-ground. A demonstration of SBC will be given.

8386-25, Session 7

Dissemination of full motion video in a tactical network

F. R. Carlson, U.S. Army Battle Command Battle Lab.-Gordon (United States)

Basically, FMV entered the theater in 3 ways - GBS-IP, GBS-DVB-RCS, and Organically Generated Video. The issue was that there was no real way to pass the very high data rate video across a SATCOM based network. We solved this problem by stripping out the multicast feeds coming from GBS and DVB-RCS into it's organic video Signal and then passing it back into a step down Video Encoder in to a second, stepped down, multicast feed. We then compressed the static traffic (email, web) coming from our TDMA and FDMA links and invoking two multicast schemes - IGMP/CGMP with PIM-SM on the pure tactical (WIN-T) networks and MSDP along the theater specific links. This solution worked but created some interesting traffic and routing management issues for the rest of that Tour.

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SPIE Defense, Security+Sensing

8387-01, Session 1

A layered control architecture for single-operator control of heterogeneous unmanned system teams

S. Buerger, J. Neely, C. Q. Little, W. Amai, R. Joyce, Sandia National Labs. (United States)

Widespread adoption of aerial, ground and sea-borne unmanned systems (UMS) for national security applications provides many advantages; however, effectively controlling large numbers of UMS in complex environments with modest manpower is a significant challenge. Currently, a control architecture and associated control methods are under development to allow a single user to control a team of multiple heterogeneous UMS as they conduct multi-faceted (i.e. multi-objective) missions in real time. The control architecture is hierarchical, modular and layered and potentially enables the use of a wide variety of control tools developed by our team and by others. The architecture provides for autonomous control of each UMS while enabling operator interaction at each layer, thus ensuring the human operator is in intimate control of the unmanned team at all times, both orchestrating high level behaviors and adjusting lower level behaviors. Simulation results will be presented that demonstrate heterogeneous UMS teams conducting multi-objective missions using multiple control techniques including a novel, layered application of distributed model predictive control as well as potential field methods. In addition, experimental results will be presented on multiple heterogeneous unmanned ground vehicles and moving cameras. Behaviors include achieving camera coverage of a region, approaching targets, and other tasks. The operator interacts with the system through a 3D user interface and has access to data from sensors on each UMS in real time. Future work will focus on interacting with dynamic targets, integrating alternative control layers, and enabling a deeper and more intimate level of real-time operator control.

8387-02, Session 1

Coordinating with humans by adjustable-autonomy for multirobot pursuit (CHAMP)

D. Dumond, J. Ayers, N. Schurr, A. Carlin, D. Burke, J. Rousseau, Aptima, Inc. (United States)

One of the primary challenges facing the modern small-unit tactical team is the ability of the unit to safely and effectively search, explore, clear and hold urbanized terrain that includes buildings, streets, and subterranean dwellings. Buildings provide cover and concealment to an enemy and restrict the movement of forces while diminishing their ability to engage the adversary. The use of robots has significant potential to reduce the risk to tactical teams and dramatically force multiply the small unit's footprint. Despite advances in robotic mobility, sensing capabilities, and human-robot interaction, the use of robots in room clearing operations remains nascent.

CHAMP is an innovative capability currently in development that casts the human-robot interaction problem as a question of adjusting autonomy in order to allow the coordination of the robotic team to become more dynamic and adjust to the goals, demands, and constraints of the current situation as it unfolds. In this way, the human operator can either give control to the robots to search autonomously, or can retain control and direct the robots where needed. CHAMP's autonomy is built upon a combination of adversarial pursuit algorithms and human recognition sensing capabilities. Multi-modal interaction with CHAMP is achieved using novel gesture-recognition based capabilities to reduce the need for heads-down tele-operation. The combination of adjustable autonomy and the gesture-based commands given by the human operator will allow the human-robot team to seamlessly work together in a room clearing situation.

8387-03, Session 1

The reconnaissance and autonomy for small robots (RASR): MAGIC 2010 challenge

A. Lacaze, K. N. Murphy, Robotic Research LLC (United States); M. Del Giorno, Del Services, LLC (United States); K. Corley, Embry-Riddle Aeronautical Univ. (United States)

The Reconnaissance and Autonomy for Small Robots (RASR) team developed a system for the coordination of groups of unmanned ground vehicles (UGVs) that can execute a variety of military relevant missions in dynamic urban environments. Historically, UGV operations have been primarily performed via tele-operation, requiring at least one dedicated operator per robot, and requiring substantial real-time bandwidth to accomplish those missions. Our team goal was to develop a system that can provide long-term value to the war-fighter, utilizing MAGIC-2010 as a stepping stone. To that end, we self-imposed a set of constraints that would force us to develop technology that could readily be used by the military in the near term:

- Use a relevant (deployed) platform
- Use low-cost, reliable sensors
- Develop an expandable and modular control system with innovative software algorithms to minimize the computing footprint required
- Minimize required communications bandwidth and handle communication losses
- Minimize additional power requirements to maximize battery life and mission duration.

8387-04, Session 1

Teleoperation control of collaborative multifunctional robotic swarms for multitask, multitarget scenarios

Y. Cheung, Stevens Institute of Technology (United States); J. Chung, K. Patel, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

So far many teleoperation systems involving cooperative multi-robots to cope with different tasks on a single target with a team of homogeneous robots have been developed with (1) modified potential field based leader-follower formation, (2) adaptive multi-robotic impedances, and (3) compensation for contact forces. However, most of the homeland security applications, e.g. military reconnaissance, exploration, and etc, need a team of heterogeneous robots to work on the multi-task simultaneously on the multi-target with a robot-task-target pairing. Therefore, the main contribution of this paper is to propose the cooperative teleoperation control method integrating not only (1-3) but also the robot-task-target pairing for a multi-robot multi-task multi-target defensive application.

The robot-task-target pairing is derived from the proven auction algorithm for multi-robot multi-task multi-target cases, which optimizes effects-based robot-task-target pairing based on a heuristic algorithm. The pairing method for the robot-task-target pairing is developed to produce a weighted attack guidance table (WAGT), which includes the benefits of assignments of robotic combinations (subteams) to tasks and targets. Therefore, the optimal robot-task-target pairs are computed based on WAGT with the heuristic algorithm. Simulation studies illustrate the efficacy of the teleoperation system with the proposed control method for multi-task multi-target scenarios.

8387-05, Session 1

A feedback-trained, autonomous control system for heterogeneous search-and-rescue applications

J. Straub, The Univ. of North Dakota (United States)

Search and rescue (SAR) applications present a challenge to autonomous systems. An unknown environment must be explored with maximum possible efficiency. A multi-robot group is well suited to this type of challenge. Much of the prior research has utilized extensive teleoperation; however, this requires numerous operators and constrains system performance to operator response rates. Human operators are particularly poorly suited to directing numerous heterogeneous robots with different capabilities. Autonomous solutions have also been researched previously.

A control approach for autonomous discovery of a SAR environment is proposed in this paper. It presumes that robots will be required to both explore the environment and participate in target identification. Under this model, robots default to a random search (ground-covering) pattern; however, as prospective targets are discovered, characterization assistance is requested from other robots. A centralized dispatch and learning system (which continually refines movement time costs and other heuristics used in planning) is combined with individual robot autonomy in task ordering (based on existing task proximity and priority and local conditions).

An environment analogous (from a control perspective, only) to a SAR situation was created and multiple robots were used to characterize it with limited sensors. The control technique presented is extensible to most sensor types. Human assisted sensing (i.e., visual target identification) can also be integrated in to this model and is discussed. While this control methodology is not a fully autonomous solution, it removes human operators from control tasks and allows them to focus on areas of strength such as perception.

8387-06, Session 1

Spatial grasp technology and its application to distributed robotized systems

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

A novel philosophy and accompanying high-level distributed control technology will be revealed that can effectively combat asymmetric situations with a massive use of unmanned systems. Traditional approaches create system structure and its internal organization first, and only then try to get its needed global behavior, which often results in system's inflexibility of reacting on rapidly changing goals. We are offering an alternative way where can, in a special high-level formalism, directly grasp the semantics of tasks to be solved in distributed environments, while omitting numerous system organization routines which can be shifted to automated up to fully automatic levels. This may result in a highest possible adaptability to unpredictable events, paving the way to a broad use of unmanned units and their collectives (swarms). The latter can be engaged evolutionary as the formalism, expressed in Distributed Scenario Language (DSL) operating directly in distributed physical spaces with both information and matter, is suitable for both humans and robots, thus simplifying their mutual understanding & communication, as well as gradual transition to fully unmanned solutions. The compact DSL scenarios, capable of being created on the fly, are injected from any intelligent module (DSL interpreter, dynamically networked with similar ones in other units) and then split, modify, replicate and self-spread throughout the whole system, creating distributed operational infrastructures and properly orienting local and global behavior. Details of DSL and its networked interpreter will be revealed along with a variety of programming examples from different domains (ground, aerial, maritime, and space). http://isarob.org/index.php?main_page=invited_speakers.

8387-07, Session 2

Autonomous 3D exploration and mapping with unmanned ground robots

J. G. Rogers III, Georgia Institute of Technology (United States); E. A. Stump, S. H. Young, L. C. Sadler, U.S. Army Research Lab. (United States); H. I. Christensen, Georgia Institute of Technology (United States)

Unmanned vehicle systems (UVS) can be used to provide situational awareness to first responders. Current 2D mapping technology is unable to adequately represent elevation transitions in multi-story structures or represent detail that exists outside of a single plane in the environment.

Recent advancements in 3D sensing technologies enable algorithms for teams of autonomous agents to build 3D maps of the environment. These 3D maps can be used by human operatives to plan and coordinate ground operations with rich information while minimizing risk to personnel.

The mapping system presented in this paper makes 3D measurements of features in the environment. These measurements are optimized in a graph to determine the structure of the environment and the trajectory of the robot. The robot autonomously moves through the environment using a frontier-based exploration strategy with optional multirobot coordination.

Full 3D maps are generated by rendering sensor data along the robot's optimized trajectory, which can be used for operational planning.

These algorithms have been implemented on a iRobot PackBot system that has been augmented with an onboard computer and a 3D sensor suite consisting of actuated 2D laser scanners, 3D laser scanners, and RGB-D cameras.

Experimental evaluation has been conducted at a US military MOUT site which simulates the challenges in modern urban warfare. The robot is tasked to autonomously explore each of the structures at the MOUT site; the resulting maps are compared in terms of topological veridicality as well as metrical accuracy to surveyed maps.

8387-08, Session 2

Fast online learning of control regime transitions for adaptive robotic mobility

B. M. Yamauchi, iRobot Corp. (United States)

We have developed a new technique, Dynamic Threshold Learning (DTL), for rapidly learning robot control behaviors. DTL models nonlinear control problems as sets of linear control regimes bounded by nonlinear transitions in state-action space. A DTL-based robot controller starts with a set of reactive behaviors, observes how the robot interacts with the world using these behaviors, and learns which combinations of states and actions lead to undesirable control regimes. DTL quickly learns the boundaries between control regimes and modifies the robot's actions to remain within the desired control regime. As part of the DARPA-funded Dynamo Project, we have applied DTL to learn behaviors to control simulated race cars using the open-source TORCS (The Open Race Car Simulator) software package. We have developed a DTL-based controller that learns to prevent understeer and oversteer while driving a simulated race car at speeds up to 210 kph (180 mph). We have applied DTL in the real world to learn how to prevent an iRobot PackBot from rolling over in rough terrain. We have also used DTL to learn a behavior that allows the PackBot to use its manipulator arm to actively shift its center-of-gravity. This behavior allows the PackBot to climb over obstacles that would otherwise be impossible to drive over. Unlike other learning algorithms that may take hours and hundreds of trials to converge on a solution, DTL is typically capable of learning control behaviors in a few minutes with a small number of trials.

8387-09, Session 2

Safe operations of unmanned systems for reconnaissance in complex environments (SOURCE): a year later

N. J. Kott III, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); E. Mottern, General Dynamics Robotic Systems (United States); J. P. Gray, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

A year later, the Safe Operations of Unmanned systems for Reconnaissance in Complex Environments (SOURCE) program is developing and has demonstrated Perception, Intelligence, Control and Tactical Behavior technologies that are required for autonomous collaborative unmanned systems. Ultimately, soldiers will be utilized to conduct safe operation testing scenarios in cluttered dynamic environments using Autonomous Navigation System (ANS) perception and processing hardware as well as software. These ANS technologies are installed on a TARDEC developed testbed, the Autonomous Platform Demonstrator (APD).

Operating autonomously around dynamic objects is the most difficult aspect of land based autonomous navigation. These dynamic objects include other vehicles, animals and humans, with detection of human pedestrians being the most critically important. Humans present a particularly difficult detection challenge due to the diversity of sizes and postures they can present in a scene. Occlusions such as buildings or foliage, either for intentional camouflage or otherwise, complicate this challenge. To detect these dynamic objects, SOURCE will utilize ARL/GDRS developed moving obstacle detection algorithms that will run on the ANS hardware. These algorithms use data from multiple sensors including LADAR, Electro optic, and MMWR to produce detections. This limits erroneous identification that can be found when using only one sensor.

Through a series of successful Concept and Technology Demonstrations, Technical Feasibility Tests, and System Development and Demonstrations, SOURCE will be on the cusp of breaking through the robotic military culture of full-time operator control to an autonomous state. The second experiment was successfully completed in November 2011 at Camp Lejeune North Carolina.

8387-10, Session 2

Challenges to autonomous navigation in complex urban terrain

J. P. Gray, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); E. Mottern, General Dynamics Robotics Systems (United States); N. J. Kott III, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

In the field of military Unmanned Ground Vehicles (UGV), military units are adapting their concept of operations to focus on their mission capabilities within populated cities and towns. These types of operations are referred to as MOUT (Military Operations on Urban Terrain). As more Soldiers seek to incorporate technology to enhance their mission capabilities, there then becomes a need for UGV systems to encompass an ability to autonomously navigate through urban terrains. Autonomous systems have the potential to increase Soldier safety by mitigating the risk of unnecessary enemy exposure during routine urban reconnaissance.

This paper presents the development and methodology that the military has sought to increase mission capabilities through incorporating autonomy into manned/unmanned ground vehicles. The presented solution that has been developed through the Safe Operations of Unmanned systems for Reconnaissance in Complex Environments (SOURCE) Army Technology Objective (ATO) has the ability and has been tested to safely navigate through complex urban environments. This paper will also focus on the challenges the military has faced to develop the presented autonomous UGV.

8387-11, Session 3

Comparison of information theoretic functions to moving targets

W. Lu, S. Ferrari, Duke Univ. (United States); T. A. Wettergrn, Naval Undersea Warfare Ctr. (United States); R. O. Fierro, M. Anderson, The Univ. of New Mexico (United States)

Submitted for the Special Session on Intelligent Behaviors

The problem of estimating multiple moving target state has a number of applications, such as unmanned craft monitoring, wild animal observation, and suspect surveillance. In this paper, information theoretic functions for moving target state estimation are compared. A nonholonomic unicycle model with multiple known turning rates is applied to the maneuvering targets. The sequence of turning rates is modeled as a semi-Markov jump process. A semi-Markov jump process only has the Markov property at instants of jumps, and the process during the sojourn time between jumps does not necessarily have Markov property. We assume that the whole workspace is visible to a position-fix sensor, which is model as a probability density function. The sensor can take measurements of up to M regions in the workspace and returns true or false for each region. True represents belief that at least one target is in this region, while False represents belief that no target is in this region. The size of a region is assumed known and fixed. The objective is to estimate the number and the state of total targets, and to minimize energy consumption due to sensor measurements. Approximate dynamic programming (ADP) and information theoretic functions are used to optimize the selections of M regions over next N time steps. The information theoretic functions such as Shannon entropy extension, Reny information divergence, especially the Kullback-Leiber divergence or relative entropy, Fisher Information, and mutual information are compared for estimating the state and number of multiple targets in the scenario described above.

8387-12, Session 3

Enabling civilian applications of unmanned teams through intelligent collaboration, cooperation, and sensing

A. Moses, M. J. Rutherford, K. P. Valavanis, Univ. of Denver (United States)

Hardware platforms for unmanned aerial and ground vehicles are becoming increasingly commoditized, leading to low prices and high-quality equipment. This, in turn, is enabling the use of low-cost unmanned vehicles for broadening array of civilian and commercial applications. In this paper we consider a heterogeneous group consisting of 5 ground vehicles and 2 aerial vehicles. Using this standard “team,” we describe and analyze five different civilian applications to which the team is well suited, and for which existing solutions are either too costly or not effective; the applications are drawn from scenarios in the areas of customs and border protection, infrastructure surveillance, early fire detection, and public safety incident response. For each application, we study the vehicle capabilities, the power budget, the sensor suite, the intelligent data processing required of each vehicle, intra-team communication requirements, and any ground / operator station requirements. The focus is on solutions that require collaboration and cooperation between vehicles, and synthesis of the heterogeneous sensor data they provide.

8387-13, Session 3

Trust methods for multi-agent consensus

D. G. Mikulski, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); F. L. Lewis, The Univ. of Texas at Arlington (United States); E. Y. Gu, Oakland Univ. (United States); G. R. Hudas, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

Submitted for the Special Session on Intelligent Behaviors. Chairs: Greg Hudas and F.L. Lewis. Trust can be thought of as a highly versatile heuristic that helps us deal with uncertainty by reducing perceived complexities within situations involving risk, vulnerability, and interdependence. Generally, the optimism to believe that things will behave consistently motivates the use of trust, even if it exposes one to undesirable possibilities. For the consensus problem in multi-agent systems, it is often assumed that all agents are equally trustworthy to seek agreement. But for multi-agent military applications - particularly those that deal with sensor fusion or multi-robot formation control - this assumption may create the potential for compromised network security or poor cooperative performance. As such, in this paper, we present the application of novel trust-based solutions for the multi-agent consensus problem. In doing so, we propose a new, practical algorithm to calculate trustworthiness in local agents using observations and statistical inferences from various historical perspectives. We also propose a new trust-based consensus protocol and prove its asymptotic convergence in strongly connected digraphs. We conclude by analyzing the multi-agent consensus problem in terms of a cooperative trust game to understand coalition formation dynamics during convergence.

8387-14, Session 3

Intelligent behaviors through vehicle-to-vehicle and vehicle-to-infrastructure communication

R. D. Garcia, M. Brown, P. Sturgeon, Southwest Research Institute (United States)

The last decade has seen a significant increase in intelligent safety devices on private automobiles. These devices have both increased and augmented the situational awareness of the driver and in some cases provided automated vehicle responses. To date, almost all intelligent safety devices have relied on data directly perceived by the vehicle. This constraint has a direct impact on the types of solutions available to the vehicle. In an effort to improve the safety options available to a vehicle, numerous research laboratories and Government agencies are investing time and resources into connecting vehicles to each other and to static infrastructure devices.

This work details several efforts in both the commercial and private auto industry to increase vehicle safety and driver situational awareness through vehicle-to-vehicle and vehicle-to-infrastructure communication. It will specifically discuss intelligent behaviors being designed to auto disable non-compliant vehicles, warn tractor trailer vehicles of potentially hazardous roadways and maneuvers (e.g. stalled vehicle in lane, occupied blind spot and approaching roadwork vehicle) and alert drivers to nonline-of-sight emergencies. Results of various simulation and real world experiments will be presented along with corresponding algorithms.

8387-15, Session 3

Multi-destination UGV navigation planning in coordinate-free and localization-free wireless sensor and actuator networks

G. Zhang, C. Duncan, J. Kanno, R. R. Selmic, Louisiana Tech Univ. (United States)

We consider a distributed, self-healing and coordinate-free Wireless Sensor and Actuator Network (WSAN), which is deployed in an ad-hoc fashion, and a constant number of mobile Unmanned Ground Vehicles (UGVs). This paper addresses the problem of UGV(s) navigation in the WSAN when multiple destinations arise within the same time period. Before proceeding with the control algorithm, two preliminary steps are carried out. First, we eliminate possible duplication of UGV destinations. Each destination can be a set of nodes that report the same event of interest. Since a global map is not available, multiple nodes can detect the same event and erroneously declare themselves as distinct destinations. We use a leader election algorithm to remove these duplicates. Second, we propose a hop-distance assignment algorithm, by which each node stores hop-distances from corresponding destinations. The hop-distance is used as a distance measure in a coordinate-free and localization-free network. Finally, we formulate the multi-UGV and multi-destination navigation planning problem as a task allocation problem, where we consider each UGV to be an agent and each destination a task. Since even for the special case of a single UGV, the problem, being similar to the well-known traveling salesman problem, is NP-complete, we present a navigation control algorithm that is sub-optimal with regard to the total distance traveled by the UGV. By having the UGV communicate limited status information with other neighboring UGVs and having each UGV solve an integer linear programming problem to choose their optimal destination, the algorithm avoids convergence of multiple UGVs to the same destination. In the special case of a single UGV in the network, we use a greedy algorithm to determine the order to visit destination nodes. For this case, we present an upper bound on the approximated solution in terms of the overall distance traveled. In both algorithms, we analyze the communication complexity and present simulation examples.

8387-16, Session 3

Neural network-based navigation and control of unmanned aerial vehicles for detecting unintended emissions

H. Zargarzadeh, Missouri Univ. of Science and Technology (United States)

Unmanned Aerial Vehicles (UAVs) are versatile aircraft with many defense applications, including the potential for use to detect unintended electromagnetic emissions from electronic devices. A particular area of recent interest for both military and law enforcement applications has been helicopter unmanned aerial vehicles. Because of the nature of these helicopters' dynamics, high-performance controller design for them presents a challenge. This paper introduces an optimal controller design via output feedback control for trajectory tracking of a helicopter UAV using a neural network (NN). The output-feedback control system utilizes the backstepping methodology, employing kinematic, virtual, and dynamic controllers and an observer. The online approximator-based dynamic controller learns the infinite-horizon Hamilton-Jacobi-Bellman (HJB) equation in continuous time and calculates the corresponding optimal control input to minimize the HJB equation forward-in-time. Optimal tracking is accomplished with a single NN utilized for cost function approximation. The controller positions the helicopter, which is equipped with an antenna, such that the antenna can detect unintended emissions. The overall closed-loop system stability is demonstrated using Lyapunov analysis. Finally, results are provided to demonstrate the effectiveness of the proposed control design for positioning the helicopter for unintended emissions detection.

8387-17, Session 4

Designing the common controller

D. N. Powell, Space and Naval Warfare Systems Ctr. Pacific (United States)

Human factors engineering drives user interfaces to an integrated design while project-specific data requirements complicate the design

of a common controller for all vehicles. Supporting changes to the user interface is often handled by using configuration files while new external data connections are often managed with software modularity. Many system designs require the data conform to an internal representation for the user interface to categorize into a tiled display. Project-specific customization is impeded by the implicit rules introduced by the internal data representation. Space and Naval Warfare Systems Center, Pacific (SSC-PAC) developed version 3 of the Multi-robot Operator Control Unit (MOCU) to address interoperability, standardization, and customization issues by using a modular, scalable, and flexible architecture. MOCU version 3 provides an open and extensible operator control interface that allows additional functionality to be seamlessly added with software modules while providing the means to fully integrate the information into a layered, game-like user interface. MOCU's design allows it to completely decouple the human interface from the core management modules, while still allowing modules to draw to overlapping regions of the screen without interference or a priori knowledge of other display elements, thus allowing even more flexibility in project-specific customization.

8387-18, Session 4

A monocular leader-follower system for small mobile robots

C. Monnier, S. German, A. Ostapchenko, Charles River Analytics, Inc. (United States)

Current generation UGV control systems typically require operators to manually and continuously control a platform through teleoperation, even for simple tasks such as travelling between locations. While vision-based control technologies promise to significantly reduce the burden on UGV operators, most schemes rely on specialized sensing hardware, such as LIDAR or stereo cameras, or require additional soldier-worn equipment or markers to differentiate the leader from nearby pedestrians. We present a system for robust leader-follower control of small UGVs using only a single monocular camera, which is ubiquitous on mobile platforms. The system allows a user to control a mobile robot by leading the way and issuing commands through arm/hand gestures, and differentiates between the leader and nearby pedestrians. Our framework achieves this through efficient extraction and re-use of visual features across the pedestrian detection, appearance learning, and gesture recognition algorithms that comprise the system.

8387-19, Session 4

Seamless human-machine control coordination for semi-autonomous obstacle avoidance in unmanned ground vehicles

S. Anderson, S. Karumanchi, Massachusetts Institute of Technology (United States); B. Johnson, V. E. Perlin, M. Rohde, Quantum Signal LLC (United States); K. D. Iagnemma, Massachusetts Institute of Technology (United States)

Unmanned or "teleoperated" vehicles are increasingly being used in a variety of military functions, from surveillance and reconnaissance to the detection and removal of hazardous materials. While advantageous in many respects over their manned counterparts, these vehicles also pose unique challenges when it comes to safely avoiding obstacles. Not only must operators of these vehicles cope with the difficulties inherent to the manned driving task, but they must also perform many of the same functions with a restricted field of view, limited depth perception, potentially disorienting camera viewpoints, and significant time delays. In this work, a method for enhancing operator performance by seamlessly coordinating human and controller commands to ensure that the vehicle avoids obstacles and maintains stability is presented. This method uses LIDAR sensing to identify and localize environmental hazards. Constraints are then placed to bound the edges of a hazard-free corridor, and the optimal trajectory satisfying those constraints is calculated to estimate the threat posed by the current situation. Based on this threat, the semi-autonomous controller intervenes as necessary to ensure that the vehicle avoids collisions and loss of stability while allowing the human operator to control the vehicle when - and to the degree that - his/her inputs are safe. This system's performance is demonstrated via off-road teleoperation of a Kawasaki Mule in an open field among obstacles. In these tests, the system safely avoids collisions and maintains vehicle stability even in the presence of "routine" operator error, loss of operator attention, and complete loss of communications.

8387-20, Session 4

Study of high-definition and stereoscopic head-aimed vision for improved teleoperation of an unmanned ground vehicle

D. R. Tyczka, R. Wright, B. Janiszewski, M. J. Chatten, Chatten Associates, Inc. (United States); T. A. Bowen, B. K. Skibba, U.S. Air Force Materiel Command (United States)

Nearly all explosive ordnance disposal robots in use today employ monoscopic standard-definition video cameras to relay live imagery from the robot to the operator. With this approach, operators must rely on shadows and other monoscopic depth cues in order to judge distances and object depths. Alternatively, they can contact an object with the robot's manipulator to determine its position, but that approach carries with it the risk of detonation from unintentionally disturbing the target or nearby objects.

We recently completed a study in which high-definition (HD) and stereoscopic video cameras were used in addition to conventional standard-definition (SD) cameras in order to determine if higher resolutions and/or stereoscopic depth cues improve operators' overall performance of various unmanned ground vehicle (UGV) tasks. We also studied the effect that the different vision modes had on operator comfort. A total of six different head-aimed vision modes were used including normal-separation HD stereo, SD stereo, "micro" (reduced separation) SD stereo, HD mono, and SD mono (two types). In general, the study results support the expectation that higher resolution and stereoscopic vision aid UGV teleoperation, but the degree of improvement was found to depend on the specific task being performed; certain tasks derived notably more benefit from improved depth perception than others. This effort was sponsored by the Joint Ground Robotics Enterprise under Robotics Technology Consortium Agreement #69-200902 T01. Technical management was provided by the U.S. Air Force Research Laboratory's Robotics Research and Development Group at Tyndall AFB, Florida.

8387-21, Session 4

Control solutions for robots using android devices

A. W. Evans, U.S. Army Research Lab. (United States); J. P. Gray, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); D. Rudnick, DCS Corp. (United States); R. E. Karlsen, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

As more Soldiers seek to utilize robots to enhance their mission capabilities, controls are needed which are intuitive, portable, and adaptable to a wide range of mission tasks. Android devices have the potential to meet each of these requirements as well as being based on readily available hardware. This paper will focus on some of the ways in which an Android device could be used to control specific and varied robot mobility functions and payload tools. Several small unmanned ground vehicle (SUGV) payload tools will have been investigated at Camp Pendleton during a user assessment and mission feasibility study for automatic remote tool changing. This group of payload tools will provide a basis, to researchers, concerning what types of control functions are

needed to fully utilize SUGV robotic capabilities. Additional, mobility functions using tablet devices have been used as part of the SOURCE ATO which is investigating the safe operation of robotics.

Using Android and other hand-held devices is not a new concept in robot manipulation. However, the authors of this paper hope to introduce some novel concepts that may serve to make the interaction between Soldier and machine more fluid and intuitive. By creating a better user experience, Android devices could help to reduce training time, enhance performance, and increase acceptance of robotics as valuable mission tools for Soldiers.

8387-22, Session 4

Development and human factors analysis of an augmented reality interface for multirobot, tele-operation, and control

S. Y. Lee, N. P. Lucas, R. D. Ellis, A. K. Pandya, Wayne State Univ. (United States)

This paper presents a seamlessly controlled human multi-robot system comprised of ground and aerial robots of semi-autonomous nature for source localization tasks. The system combines augmented reality interfaces capabilities with human supervisor's ability to control multiple robots. The role of this human multi-robot interface is to allow an operator to control groups of heterogeneous robots in real time in a collaborative manner. This interface used overhead camera view from aerial vehicles to allow the operator to direct each robot individually or in groups. It also used advanced path planning algorithms to ensure obstacles are avoided and that the operators are free for higher-level tasks. Each robot knows the environment and obstacles and can automatically generate a collision-free path to any user-selected target. It displayed sensor information from each individual robot directly on the robot in the video view. In addition, a sensor data fused AR view is displayed which helped the users pin point source information or help the operator with the goals of the mission. The paper studies a preliminary Human Factors evaluation of this system in which several interface conditions are tested for source detection tasks. Results show that the novel Augmented Reality multi-robot control (Point-and-Go and Path Planning) reduced mission completion times compared to the traditional joystick control for target detection missions. Usability tests and operator workload analysis are also investigated.

8387-23, Session 7

Large-scale experimental design for decentralized SLAM

A. G. Cunningham, F. Dellaert, Georgia Institute of Technology (United States)

This paper presents an analysis of large scale decentralized SLAM under a variety of experimental conditions to illustrate design trade-offs relevant to multi-robot mapping in challenging environments. As a part of work through the MAST CTA, the focus of these robot teams is on the use of small-scale robots with limited sensing, communication and computational resources. To evaluate mapping algorithms with large numbers (50+) of robots, we developed a simulation incorporating sensing of unlabeled landmarks, line-of-sight blocking obstacles, and communication modeling. Scenarios are randomly generated with variable models for sensing, communication, and robot behavior.

The underlying Decentralized Data Fusion (DDF) algorithm in these experiments enables robots to construct a map of their surroundings by fusing local sensor measurements with compressed map information from neighboring robots. Each robot maintains a cache of previously collected compressed maps from neighboring robots, and actively distributes these maps throughout the network to ensure resilience to communication and node failures. We bound the size of the robot neighborhoods to control the growth of the size of neighborhood maps.

We present the results of experiments conducted in these simulated scenarios under varying measurement models and conditions while measuring mapping performance. We measure the performance of the system, including optimization time and map accuracy in both local and neighborhood optimization, and communication loads. The results highlight the trade-offs between mapping performance and scenario design, including multi-robot loop closure, robot teams separating and joining, multi-robot data association, exploration bounding, neighborhood sizes, and communication and robot failure recovery.

8387-24, Session 7

Real-time, lidar-based place recognition using distinctive shape descriptors

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A key component in the emerging localization and mapping paradigm is an appearance-based place recognition algorithm that detects when a place has been revisited. This algorithm can run in the background at a low frame rate and be used to signal a metric mapping algorithm when a loop is detected. An optimization technique can then be used to correct the map by 'closing the loop'. This allows autonomous UGV to improve localization and map accuracy and successfully navigate large environments. Image-based place recognition techniques lack robustness to sensor orientation and varying lighting conditions. Additionally, the quality of range estimates from monocular or stereo imagery can decrease the loop closure accuracy. Here, we present a lidar-based place recognition system that is robust to these challenges. This probabilistic framework learns a generative model of place appearance and determines whether a new observation comes from a new or previously seen place. Highly descriptive features called the Variable Dimensional Local Shape Descriptors are extracted from lidar range data to encode environment features. The range data processing has been implemented on GPU to optimize performance. The system runs in real-time on a military research vehicle equipped with a highly accurate, 360 degree field of view lidar and can detect loops regardless of the sensor orientation. Promising experimental results are presented for both rural and urban scenes in large outdoor environments.

8387-25, Session 7

Fully self-contained, vision-aided navigation and marker-free landing of a micro-air vehicle independent from external sensor inputs

R. Brockers, L. H. Matthies, Jet Propulsion Lab. (United States)

Direct-lift micro air vehicles have important applications in reconnaissance. In order to conduct persistent surveillance in urban environments, it is essential that these systems can perform autonomous landing maneuvers at high vantage points without the help of any external sensor and with a fully contained on-board software solution. In this paper, we present a micro air vehicle that uses vision feedback from a single down looking camera to navigate autonomously and detect an elevated landing platform as a surrogate for a roof top. Our method requires no special preparation (labels or markers) of the landing location. Rather, leveraging the planar character of urban structure, the landing platform detection system uses a planar homography decomposition to detect landing targets and produce approach waypoints for autonomous landing. The vehicle control algorithm uses a Kalman filter based approach for pose estimation to fuse visual SLAM (PTAM) position estimates with IMU data to correct for high latency SLAM inputs and to increase the position estimate update rate in order to improve control stability. Scale recovery is achieved using inputs from a sonar altimeter. In experimental runs, we demonstrate a real-time implementation running on-board a micro aerial vehicle that is fully self-contained and independent from any external sensor information. With this method, the

vehicle is able to search autonomously for a landing location and perform precision landing maneuvers on the detected targets.

8387-26, Session 7

Field evaluation of a prototype optical instrument for airborne sense-and-avoid applications

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A prototype wide-field optical (vis-near IR) sense-and-avoid instrument, configured as a network of smart camera nodes, was constructed from low-cost commercial off-the-shelf (COTS) components. In order to avoid small, general-aviation aircraft in a timely manner, such a sensor must detect targets at a range of 5-10 km at an update rate of a few Hz. Key performance issues include the mixing of target and background signals through the sensor transfer function, atmospheric scattering, ground clutter and direct sunlight illumination.

Field measurements were conducted using a prototype instrument platform consisting of an optical sensor co-mounted rigidly with a suite of aircraft navigation instruments: A Honeywell HG1700 inertial measurement unit (IMU) and a GPS. System power was aircraft-compatible 28 VDC. The prototype sensor consisted of a cluster of smart camera nodes connected via Ethernet. For the current ground-based measurements, only five camera nodes were needed to cover the field-of-view of interest, and the target performed various maneuvers within this field of view. A fully instrumented helicopter was used as the target aircraft, and sensor imagery was recorded at 3 Hz for multiple flight paths. The collected images were synchronized with ancillary target data (position, orientation, velocity) and local meteorological data, with analysis conducted offline.

Figures of merit for the analysis include probability of detection (P_d), signal-to-noise ratio (SNR), range at first detection (R_0) and false alarm rate (FAR). Analysis included the determination of R_0 with regards to SNR, Pd and FAR. Using the images, estimates were derived of atmospheric attenuation, sensor transfer function and target range. A comparison of image processing techniques to enhance R_0 was provided. The concept of “image processing advantage” was discussed, in order to quantify the benefits of local (node) computing.

8387-27, Session 7

Saliency detection and model-based tracking: a two-part vision system for small-robot navigation in forested environment

R. Roberts, D. H. Ta, Georgia Institute of Technology (United States); J. Straub, Technische Univ. München (Germany); K. Ok, F. Dellaert, Georgia Institute of Technology (United States)

We address the problem of visual perception for small robots, with the goal of supporting navigation and path-planning in outdoor environments. This is an important and still largely unsolved problem, as traditional robot perception approaches either require heavy and power-hungry sensors that are not feasible on small robots, or produce information that ill-suited for path-planning. In this paper we present preliminary results of our two-part perception system for a small robot moving through a forest, which builds a local map of the tree trunks. Instead of a detailed 3D model or complex point cloud, we model tree trunks as vertical cylinders, so that our map contains low-dimensional geometric primitives, which are suitable proxies an can better support navigation, obstacle avoidance, and path-planning algorithms. Our system consists of an optical-flow based saliency detector and rotation estimator that detects nearby important objects, and a second subsystem that then builds a local map of nearby tree trunks using state of the art graphical model inference by the GTSAM library. We demonstrate the potential of our approach with data captured from a challenging, forested environment.

8387-28, Session 7

Multiple object detection and tracking on the uneven terrain using multiple lidar for UGV

K. Cho, Univ. of Science & Technology (Korea, Republic of); S. Baeg, S. Park, Korea Institute of Industrial Technology (Korea, Republic of)

In this paper, we describe a method for the multiple object detection and tracking on an uneven terrain in the forest for unmanned ground vehicles. Localization is essential for the object detection and tracking. In these environment, an high-cost INS and D-GPS are contaminated by uncertain measurement. For example, gps signal is weak and non-plain terrain makes a lot of noise into odometry. In the verdant forest, the occlude trees make a hard to measure and decide to objects for a LIDAR. Our system has a navigation map which is composed with detected natural objects; trees, bushes etc. Based on this map, we generate the path with previous detected and registered objects. We use RANSAC and fuzzy c-mean clustering for an object detection and extended kalman filter for an object tracking. We compare the result with multiple/single channel LIDAR sensors and verify our method using a consistency map.

8387-29, Session 8

Foundations of autonomy for ground robotics

J. A. Bornstein, U.S. Army Research Lab. (United States); R. R. Mitchell, General Dynamics Robotic Systems (United States)

Unmanned systems have become a critical element of the Army’s Force Structure for applications such as Emergency Ordnance Disposal (EOD). Systems currently fielded are typically teleoperated and thus impose significant cognitive burden upon the operator. The robotics CTA, a collaborative research endeavor between the Army Research Laboratory and a consortium of eight industrial and academic partners, is developing fundamental technology to enable a new level of autonomous capability for future unmanned systems that can act as teammates to soldiers making up a small unit. The Alliance is focusing research in five key areas: a cognitively based world model, semantic perception, learning, meta-cognition, and adaptive behaviors. Because current world model representations are relatively shallow, metrically based, and support only brittle behaviors, the CTA is creating a cognitive-to-metric world model that can incorporate and utilize mission context. Current perceptual capabilities for unmanned systems are generally limited to a small number of well defined objects or behaviors. The CTA is raising perception to a semantic level that enables understanding of relationships among objects and behaviors. To successfully team with small units, the command and control of unmanned systems must move away from the current hardware controller paradigm to one of verbal and gestural communication, implicit cues, and transparency of action between soldier and robot. The CTA is also exploring adaptive behavior and mechanics that will permit manipulation of arbitrarily shaped objects, animal-like mobility in complex environments, and conduct of military missions in dynamic tactical conditions. Efforts to incorporate learning from the lowest levels of the architecture upwards are key to each of the above.

8387-30, Session 8

High degree-of-freedom dynamic manipulation

M. P. Murphy, B. Stephens, M. da Silva, A. A. Rizzi, Boston Dynamics (United States)

The creation of high degree of freedom dynamic mobile manipulation techniques and behaviors will allow robots to accomplish difficult tasks in the field. We are investigating the use of the body and legs of legged robots to improve the strength, velocity, and workspace of an integrated manipulator to accomplish dynamic manipulation. This is an especially challenging task, as all of the degrees of freedom are active at all times, the dynamic forces generated are high, and the legged system must maintain robust balance throughout the duration of the tasks. To accomplish this goal, we are utilizing trajectory optimization techniques to generate feasible open-loop behaviors for our 28 dof robot by planning the trajectories in a 13 dimensional space. Covariance Matrix Adaptation techniques are utilized to optimize for several criteria such as payload capability and task completion speed while also obeying constraints such as torque and velocity limits, kinematic limits, and center of pressure location. These open-loop behaviors are then used to generate feed-forward terms, which are subsequently used online to improve tracking and maintain low controller gains. Some initial results on one of our existing balancing quadruped robots with an additional human-arm-like manipulator are demonstrated in simulation, including dynamic lifting and throwing of heavy objects such as cinder blocks, using motions that resemble a human athlete more than typical robotic motions. Increased payload capacity is accomplished through the use of momentum and swinging techniques. Videos of the real robot performing these behaviors will be available by the conference date.

8387-31, Session 8

Laboratory on legs: an architecture for adjustable morphology with legged robots

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For mobile robots, the essential units of actuation, computation, and sensing must be designed to fit within the body of the robot. Additional capabilities will largely depend upon a given activity, and should be easily reconfigurable to maximize the diversity of applications and experiments. To address this issue, we introduce a modular architecture originally developed and tested in the design and implementation of the X-RHex hexapod that allows the robot to operate as a mobile laboratory on legs. In the present paper we will introduce the specification, design and very earliest operational data of CANID, a actively driven compliant-spined quadruped whose completely different morphology and intended dynamical operating point are nevertheless built around exactly the same “Lab on Legs” actuation, computation, and sensing infrastructure. We will review as well, more briefly a second RHex variation, the XRL platform, built using the same components.

8387-32, Session 8

Connecting a cognitive architecture to robotic perception

U. Kurup, C. Lebiere, A. Stentz, M. Hebert, Carnegie Mellon Univ. (United States)

We present an integrated architecture in which perception and cognition interact and provide information to each other leading to improved performance in real-world situations. Our system integrates the Felzenswalb et. al. object-detection algorithm with the ACT-R cognitive architecture. The targeted task is to predict and classify pedestrian behavior in a checkpoint scenario, most specifically to discriminate between normal versus checkpoint-avoiding behavior. The Felzenswalb algorithm is a learning-based algorithm for detecting and localizing objects in images. ACT-R is a cognitive architecture that has been successfully used to model human cognition with a high degree of fidelity on tasks ranging from basic decision-making to the control of complex systems such as driving or air traffic control. The Felzenswalb algorithm detects pedestrians in the image and provides ACT-R a set of features based primarily on their locations. ACT-R uses its pattern-matching capabilities, specifically its partial-matching and blending mechanisms, to track objects across multiple images and classify their behavior based on the sequence of observed features. ACT-R also provides feedback to the Felzenswalb algorithm in the form of expected object locations that allow the algorithm to eliminate false-positives and improve its overall performance. This capability is an instance of the benefits pursued in developing a richer interaction between bottom-up perceptual processes and top-down goal-directed cognition. We trained the system on individual behaviors (only one person in the scene) and evaluated its performance across a number of conditions including the presence of multiple people/objects in the scene, impaired detection and novel behaviors.

8387-33, Session 8

Semantic perception for ground robotics

M. Hebert, Carnegie Mellon Univ. (United States); M. Bajracharya, Jet Propulsion Lab. (United States); D. Bagnell, J. Cohn, Carnegie Mellon Univ. (United States); K. Daniilidis, Univ. of Pennsylvania (United States); L. H. Matthies, Jet Propulsion Lab. (United States); D. D. Morris, General Dynamics Robotic Systems (United States); P. Perona, California Institute of Technology (United States); J. Shi, B. Taskar, Univ. of Pennsylvania (United States); S. Thornton, General Dynamics Robotic Systems (United States)

Perception is concerned with converting raw sensor data into a description of the world around a UGV which can be used by planning and reasoning components. A first level of description concerns the basic mobility functions: Where can the system drive safely? While considerable progress has been made in this area, higher-level cognitive functions require more precise descriptions than labeling based on mobility needs: They need a level of “semantic perception” to name objects and features in the scene, to understand the relations between them, to understand the behaviors of other agents, e.g., other people, in the scene, and their intent.

In this paper, we review the key elements of our approach to semantic perception in the Robotics CTA program. For understanding the static environment, we use new approach to scene understanding, i.e., labeling visual data based on models of features, objects, and categories, learned from training data. These approaches are based on recent progress in efficient inference in the machine learning domain and in advances in representing visual knowledge, e.g., shape representation in images or local features in 3D point clouds. In their most general form, such scene understanding capabilities face considerable challenges: for example, huge volume of data, complexity and variability of the environment, or large number of classes. Our approach toward tackling these challenges is to take advantage of the UGV domain to constrain the perception problem. For example, we investigate a number of ways to incorporate contextual constraints, e.g., the geometric constraints induced by the structure of the urban environment in which the system operates, into the perception algorithms. For understanding the dynamic aspects of the environment, we develop robust tracking algorithms suitable for environments such as complex urban scenes. However, here too, we are interested in deriving as complete as possible a high-level, semantic description of the current scene. To that end, we develop techniques that go beyond detection and tracking of individual agents by forecasting their plausible future behavior and by incorporating high-resolution features such as posture and facial analysis that relate to social cues.

8387-34, Session 8

Robust mobility in human-populated environments

J. P. Gonzalez, General Dynamics Robotic Systems (United

States); M. Phillips, B. Neuman, M. Likhachev, Carnegie Mellon Univ. (United States)

Creating robots that can help humans in a variety of tasks requires robust mobility and the ability to safely navigate among moving obstacles. This paper presents an overview of recent research in the Robotics Collaborative Technology Alliance (RCTA) that addresses many of the core requirements for robust mobility in human-populated environments.

Anytime Repairing A* with Equivalence Classes (ARAE*) allows the use of coarse equivalence classes to quickly find trajectories in higher dimensional spaces, and then to refine these trajectories as time allows, while still producing smooth paths with provable suboptimality guarantees.

Safe Interval Path Planning (SIPP) allows for very fast planning in dynamic environments when planning time-minimal trajectories. Generalized Safe Interval Path Planning extends this concept to trajectories that minimize arbitrary cost functions. Finally, generalized PPCP algorithm is used to generate plans that reason about the uncertainty in the predicted trajectories of moving obstacles and try to actively disambiguate the intentions of humans whenever necessary.

We show how these approaches consider moving obstacles as well as kinematic, spatial and temporal constraints and produce high-fidelity paths. Experiments in simulated environments show the performance of the algorithms under different controlled conditions, and experiments on physical mobile robots interacting with humans show how the algorithms perform under the uncertainties of the real world.

8387-35, Session 8

The importance of shared mental models and shared situation awareness for transforming robots from tools to teammates

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Current ground robots are largely employed via tele-operation and provide their operators with useful tools to extend reach, improve sensing, and avoid dangers. To move from robots that are useful as tools to truly synergistic human-robot teaming, however, will require not only greater technical capabilities among robots, but also a better understanding of the ways in which the principles of teamwork can be applied from all-human teams to mixed teams of humans and robots.

A core characteristic that successful human teams demonstrate is their ability to create, maintain, and act on a shared understanding of the world and the roles of the team and its members in it. The team performance literature clearly points towards two important cornerstones for shared understanding in teams: (a) Shared mental models and (b) shared situation awareness. Consequently, we are studying how these two constructs can be measured and instantiated in mixed human-robot teams. In this paper, we report results from three related efforts that are investigating (a) through research with human participants, how human mental models of tasks and teams change as a function of the type of teammate, i.e., other humans, service animals (e.g., working dogs), or advanced automated systems (e.g., robots); (b) through computer modeling, how these human mental models can be implemented, so that they can be predictive and adopted by robots; and (c) via computer simulation, how we can simulate the interactions between human and future robotic teammates on the basis of changes in shared mental models and situation assessment.

8387-53, Poster Session

Spatial learning and temporal measurements in a low-visibility, net-enabled, GPS-denied environment

T. B. Terry, M. L. Axtell, Booz Allen Hamilton Inc. (United States)

Abstract: Successful navigation in a GPS-denied environment between two points requires an understanding of direction, time and space, relative positioning, velocity, and attitude with respect to dynamic environmental influences. Multisensor processing and fusion of data afford autonomous robotic agents the ability to navigate freely through urban settings using avoidance control, proximity detection and learned landmarks. With network-enabled integration of multi-aperture sensor data and navigation information, spatial errors are reduced allowing for improved situational awareness. When visibility is reduced because of smoke, obscurants or environmental conditions, how does a robotic agent determine its radius and acquire knowledge about its aerial and terrain parameters without receiving prior knowledge? This research evaluates the capabilities of spatial learning in a low visibility, net-enabled, GPS-denied environment using discoveries and non-traditional navigation methodologies.

8387-54, Poster Session

Video analysis for high-speed, autonomous vehicle guidance

P. Wang, P. A. Torrione, L. M. Collins, K. D. Morton, Jr., Duke Univ. (United States)

Understanding of video sequences remains a task in which the abilities of humans far exceed those of computers. However, video analysis is time-consuming and fatigue can be a factor that negatively impacts human operator performance, so it remains desirable to automate video understanding and interpretation. Applications that stand to benefit from automated video analysis include video annotation/search, surveillance/security, and autonomous control. In this work we consider the task of autonomously driving a car in semi-structured outdoor environments with no human in the loop. We use monocular video to extract information about the dynamic scene, such as the locations of other cars and road lanes. These data are combined with meta-information also extracted from the video such as the speed and a route map to autonomously drive a car in a simulated environment. Several obstacles contribute to the complexity of this problem. A moving camera presents unique challenges to scene analysis due to the ever-changing background. In addition, online control depends on processing efficiency and minimal latency. In contrast to many recent approaches to autonomous driving, we can utilize only a single monocular camera and are unable to rely on the depth and segmentation cues that could be acquired using laser range finders, radar, etc. This work explores a variety of approaches to tackle these challenges, including filtering, feature descriptors, object detection, classification, and tracking.

8387-55, Poster Session

An enhanced inertial navigation system based on low-cost IMU and laser scanner for mobile robot

H. Kim, Korea Univ. (Korea, Republic of); S. Baeg, K. Yang, Korea Institute of Industrial Technology (Korea, Republic of); K. Cho, Univ. of Science & Technology (Korea, Republic of); S. Park, Korea Institute of Industrial Technology (Korea, Republic of)

This paper describes an enhanced fusion method for an Inertial Navigation System (INS) based on a 3-axis accelerometer sensor, a 3-axis gyroscope sensor and a laser scanner. In GPS-denied Environments, indoor or dense forests, a pure INS is available for estimating odometry of mobile robot. However it has a critical implementation problem - a drift error of velocity, position and heading angle. Commonly this problem can be solved by fusing visual landmarks, a magnetometer or radio beacons. These methods do not robust in some environments a dark, fog and sunlight, an unstable magnetic field and an environmental obstacle respectively.

We proposed the solution to overcome this drift problem using Iterative

Closest Point (ICP) scan matching algorithm with a laser scanner. Our system consists of three parts. First part is an INS made-up to estimate attitude, velocity, position based on a 6-axis IMU with both 'Heuristic Reduction of gyro drift' and 'Heuristic Reduction of velocity drift' methods. Second part is frame-to-frame ICP matching algorithm to extract position and attitude by laser scan data. Third part is an extended kalman filter method for multi-sensor data fusing; INS, LIDAR.

The proposed method is very simple, robust on diverse environments. Therefore, we can reduce drift error more efficiently. The result shows to compare an odometry of the experimental result with a DGPS and pure INS.

8387-56, Poster Session

A pose estimation method for unmanned ground vehicles in GPS denied environments

A. Tamjidi, C. Ye, Univ. of Arkansas at Little Rock (United States)

This paper presents a pose estimation method based on the 1-Point RANSAC EKF (Extended Kalman Filter) framework. The method fuses the depth data from a LIDAR and the visual data from a monocular camera to estimate the pose of a Unmanned Ground Vehicle (UGV) in a GPS denied environment. Its estimation framework continually updates the vehicle's 6D pose state and temporary estimates of the extracted visual features' 3D positions. In contrast to the conventional EKF-SLAM (Simultaneous Localization And Mapping) frameworks, the proposed method discards feature estimates from the extended state vector once they are no longer observed for several steps. As a result, the extended state vector always maintains a reasonable size that is suitable for online calculation. The fusion of laser and visual data is performed both in the feature initialization part of the EKF-SLAM process and in the motion prediction stage. A RANSAC pose calculation procedure is devised to produce pose estimate for the motion model. The proposed method has been successfully tested on the Ford campus's LIDAR-Vision dataset. The results are compared with the ground truth data of the dataset and the estimation error is 2.1% of the path length.

8387-57, Poster Session

Adaptive electronic camouflage using texture synthesis

N. Pezeshkian, J. D. Neff, G. W. Anderson, Space and Naval Warfare Systems Ctr. Pacific (United States)

Camouflaged robots and leave-behind surveillance sensors are desirable in Information Surveillance and Reconnaissance operations to minimize the chances of enemy detection. Today's camouflaging techniques, however, involve nets and painted patterns that are fixed in color and geometry, limiting their use to specific environments; a fact illustrated by numerous changes in military uniforms designed to fit the latest operating environment. Furthermore, nets are bulky and can interfere with the operation or use of a robot or sensor. A more effective technique is to automatically adapt patterns and colors to match the environment, as is done by several species in nature. This can lead to the development of new and more effective robotic behaviors in surveillance missions and stealth operations. This biologically-inspired adaptive camouflage can be achieved by a) sampling the environment with a camera, b) synthesizing a camouflage image, and c) reproducing it on color electronic paper - a thin, low-power, reflective display - that is part of the outer enclosure surface of the robot or device. The focus of this paper is on the first two steps. However, the ultimate goal is to camouflage robots and leave-behind sensors using this process. The camouflage image is generated by synthesizing a color image using gray-level co-occurrence matrices (GLCMs) that produce a statistically equivalent image to the sample image. Statistic equality in color is achieved with the use of conditional probability constraints. The proof-of-concept demonstration platform comprises an embedded development board interfaced to an LCD screen and a color camera.

8387-58, Poster Session

Adaptive information interactive mechanism for multi-UAV visual navigation

H. Liu, Q. Dai, Tsinghua Univ. (China)

Multi-Unmanned Aerial Vehicle (UAV) cooperative communication for visual navigation has recently generated significant concern. It has large amounts of visual information to be transmitted and processed among UAVs with real-time requirements. And the UAV clusters have self-organized, time-varying and high dynamic characteristics. Considering the above conditions, we propose an adaptive information interactive mechanism (AIIM) for multi-UAV visual navigation. In the mechanism, the function modules for UAV inter-communication interface are designed, the mobility-based link lifetime is established and the information interactive protocol is presented. Thus we combine the mobility of UAVs with the corresponding communication requirements to make effective information interaction for UAVs. Task-oriented distributed control is adopted. In order to timely obtain the necessary visual information, each UAV can cooperate with other relevant UAVs which meet some certain terms such as situation, task or environmental conditions. Simulation results are presented to show the validity of the proposed mechanism in terms of end-to-end delay and links stability. Future research directions include the design of task cooperation algorithms to find close to optimal solutions. Also, this work takes a step closer towards cooperative communication in multi-UAV visual navigation.

8387-59, Poster Session

Mobile robot mosaic imaging of vehicle undercarriages using catadioptric vision

R. J. Ross, J. C. Devlin, S. Wang, La Trobe Univ. (Australia)

This paper describes a technique for performing imaging of car undercarriages using a mobile robot fitted with a catadioptric camera. The mobile robot follows a path, pre-computed using machine vision techniques, which trisects the undercarriage whilst the catadioptric camera sensor records a wide angle view of the undercarriage. Odometry data from the mobile robot is used to dynamically generate a region of interest, reducing the search space for template matching based image registration where the images are stitched together to form an undercarriage mosaic. For a slow moving robot (+/- 15cm/s) image registration computation time is reduced by 18%, with further reduction for faster moving robots. In addition the template matching algorithm is made rotationally invariant. In contrast to a regular camera which would require 7 passes, the proposed catadioptric imaging system can image the majority of the accessible areas of the undercarriage in 2, significantly reducing the acquisition time. The technique is verified by generating mosaics involving rotation from videos of both calibration patterns and vehicle undercarriages.

The technique allows stationary vehicle undercarriages to be imaged and shows promise for undercarriage explosive detection robots.

8387-60, Poster Session

Fuzzy logic technique for detecting communication loss in unmanned aerial vehicles

H. I. Reyes, N. Kaabouch, The Univ. of North Dakota (United States)

Unmanned aerial systems (UAVs) have recently received rapid and widespread interest for military and civil purposes. During their flights, UAVs need to communicate with both the ground stations and/or with other UAVs. This requirement implies that these vehicles rely on wireless communication links. However, due to several causes, including jamming the communication can be lost. Therefore, this paper proposes a fuzzy

logic technique to detect the loss of the UAV's communication link and determine the cause. The technique consists of testing the channel when a communication failure is detected. The test is performed by continuously sending diagnostic packages to the far end node of the link. The transmission of those packages, which lasts a determined period of time, allows the computation of three metrics: Clear Channel Assessment (CCA), RSS Received Signal Strength (RSS) and Packet Delivery Ratio (PDR). A Fuzzy Inference System (FSI) uses these parameters to compute a Jamming Index (JI). Based on the values of JI, the proposed technique establishes if either the link is functioning normally or it is lost due to a jamming attack or other causes. The performance of the proposed technique is evaluated through simulations and hardware implementations. This evaluation is done in terms of the time taken by the system to detect a failure in the link, and the percentage of miss-detections and false alarms. Evaluation results show that the proposed technique is efficient in detecting the loss of communication and determining its cause.

8387-61, Poster Session

A statistical approach for performance analysis of uncertain systems

X. Chen, Southern Univ. and A&M College (United States)

In this paper, we propose a statistical approach for analyzing the performance of uncertain systems. By treating the uncertain parameters of systems as random variables, we formulate a wide class of performance analysis problems as a general problem of quantifying the deviation of a random variable from its mean value. New concentration inequalities are developed to make such quantification rigorous and analytically simple. Application examples are given for demonstrating the power of our approach.

8387-62, Poster Session

Review of multirobot taxonomy, trends, and applications for defense and space

N. P. Lucas, Wayne State Univ. (United States) and U.S. Army Tank-Automotive and Armaments Command (United States); A. K. Pandya, R. D. Ellis, Wayne State Univ. (United States)

Multi-robot systems may be capable of performing a wide variety of distributed, hazardous, and complex tasks that are difficult or impossible for independent robots to perform. Despite significant research accomplishments and many potential benefits for defense, security, and space applications, much of the technology is still in early development.

This paper reviews influential taxonomy, research trends, and technology objectives. Anticipated defense and space applications are compared and contrasted. Parallels within and between both domains are drawn, and a classification of mission types is proposed to establish common general multi-robot system characteristics.

Recent advancements toward multi-robot systems are examined with specific emphasis on the vital areas of robot-robot interaction and human-robot interaction, including the use of virtual reality and augmented reality interfaces. An integrated concept of multi-robot interaction is proposed to draw together objectives from multi-robot and human-robot interaction research. Justification of this combined mixed-agent approach is presented on the basis of defense and space application needs.

From the substantial diversity of systems found in the field of multi-robotics, a limited set of specific defense and space multi-robot system characteristics are identified with the help of the proposed mission classification. Conclusions concerning research gaps and opportunities are drawn by examining these anticipated attributes in light of recent advancements in the field of multi-robot systems along with the proposed mixed-agent interaction approach.

8387-63, Poster Session

Videometric terminal guidance method and system for UAV accuracy landing

X. Zhou, Z. Lei, Q. Yu, H. Zhang, Y. Shang, J. Du, Y. Gui, P. Guo, National Univ. of Defense Technology (China)

We present a videometric method and system to implement terminal guidance for Unmanned Aerial Vehicle(UAV) accuracy landing. In the videometric system, two calibrated cameras put on the ground are used, and a calibration method in which at least 5 control points are applied is developed to calibrate the inner and exterior parameters of the cameras . The Cameras with 850nm optical filter are used for recognize a 850nm LED target fixed on the UAV which can make sure the target highlight in complicated background image. NNLOG(normalnized negative laplacian of gaussian) operator is developed for automatic target detection and tracking. Finally, 3-D position of the UAV with high precision can be calculated and transfered to control system to direct UAV accuracy landing. The videometric system can be work in the rate of 50Hz.

Many real flight and static precision experiments show the correctness and veracity of the method proposed in this paper, and they also indicate the reliability and robustness of the system proposed in this paper. The static precision experiment results show that the deviation is less-than 10cm when target is far from the cameras and less-than 2cm in 100m region. The real flight experiment results show that the deviation from DGPS is less-than 20cm. The system implement in this paper won the first prize in the AVIC Cup-International UAV Innovation Grand Prix, and it is the only one achieve UAV accuracy landing without GPS or DGPS.

8387-64, Poster Session

An underwater solar energy harvesting system for monitoring and security sensor applications

R. Torres, E. I. Ortiz-Rivera, Univ. de Puerto Rico Mayagüez (United States)

Underwater electric systems have limitations in special devices like sensors and semiconductors. The use of energy harvesting sources could solve this limitation, especially in low-energy sensors. Energy harvesting sources in combined with recharges batteries will extend the useful life of underwater electric systems by providing addition sources of energy and maximizing the power produced by the sources. This work proposes the use of solar cells made to supply the necessary power in low-energy sensors for underwater applications located near to the water surface. A novel dc-dc buck high efficiency converter is designed and implemented in an underwater prototype to achieve the maximum power transfer for a power load of 50mW using solar energy. The basic prototype parts consisted of small array photovoltaic cells, a dc-dc buck converter and energy storage battery. Also, maximum power point tracking techniques are applied to extract the maximum power of the solar cell and to control the power transmitted from the source to the load. The proposed solar underwater system is designed considering the different types of depth, the irradiance range of the sun during the day and different environments like pool, sea and river water. Experiments were made to analyze the behavior of the maximum power in a photovoltaic cell in different depths and loads to get the voltage range to design the converter. At the end, the solar underwater electric system satisfies not only electrical constraints but also physical constraints like small, portable and simple device assembled and tested with high power efficiency transfer.

8387-65, Poster Session

Autonomous robotic systems research project: a tool to improve undergraduate engineering education

C. I. Gonzalez, E. I. Ortiz-Rivera, Univ. de Puerto Rico Mayagüez (United States)

The University of Puerto Rico-Mayaguez has developed a strategy to improve the undergraduate engineering education by the development of autonomous robotic systems. The Autonomous Robotic System (ARoS) research project brings a synergy of computer, electrical and mechanical engineering students from the UPRM who work together to design and build two autonomous robotic systems. ARoS consider the use of existing courses at UPRM (e.g. power electronics, embedded systems, computer vision) as part of the student training without creating an extra load to the student and to the faculty. Two projects had been developed as part of ARoS: 1) micromouse, 2) autonomous quadcopter. The micromouse is a small robot mouse that is capable of finding its way from a predetermined starting point to the center of a 16×16 maze on its own and in the shortest amount of time. The autonomous quadcopter is a rotorcraft that is lifted and propelled by four rotors and has an integrated autopilot system that gives this aerial vehicle the capability of flying autonomously. The undergraduate students developed teamwork skills related to how to integrate the mechanical and electrical components that along with the software will compose each autonomous robotic system. Many undergraduate students increased their interest to enroll in advance engineering courses related to robotics, sensors, and embedded systems. The undergraduate students involved in the ARoS project, developed useful skills that in the future they can use for the development of advance unmanned systems and applications like national defense, port security, smart monitoring systems, etc.

8387-36, Session 9

Enhanced operator perception through 3D vision and haptic feedback

R. Edmondson, Polaris Sensor Technologies, Inc. (United States); K. Light, A. Bodenhamer, U.S. Army Research Lab. (United States); P. Boscher, L. Wilkinson, Harris Corp. (United States)

In September 2011 the Fort Leonard Wood Field Element of the US Army Research Laboratory - Human Research and Engineering Directorate, in conjunction with Polaris Sensor Technologies (Polaris) and Harris Corporation (Harris), evaluated the objective performance benefits of Polaris' stereo vision (3D) upgrade kit and Harris' haptic manipulation system. The experiment was conducted using the TALON small unmanned ground vehicle (SUGV). The Polaris upgrade kit is a field-upgradable set of two stereo-cameras and a flat panel display. The Harris haptic manipulation system provides seven degrees of freedom and the ability to feel remote objects via end-of-arm force sensing and a state-of-the-art haptic (force feedback) controller. Using two TALON(r) robots, one with the standard factory arm and operator control unit (OCU), and one with the Harris system arm (both were equipped with the 3D vision system), nine active-duty Army Soldiers completed four scenarios designed to be representative of missions performed by military SUGV operators. Various objective metrics including mission time and number of faults were collected, as well as subjective assessment via post mission operator surveys. The NASA Task Load Index (TLX) was also used to assess the benefit of the combined 3D and Haptic system. Results of the experiment will be reported.

8387-37, Session 9

Autonomous urban reconnaissance ingress system (AURIS): providing a tactically relevant, autonomous door-opening kit for unmanned ground vehicles

D. J. Shane, M. Rufo, Boston Engineering Corp. (United States); M. D. Berkemeier, J. A. Alberts, Autonomous Solutions, Inc. (United States)

The Autonomous Urban Reconnaissance Ingress System (AURIS) addresses a significant limitation of current military and first responder robotics technology: reconnaissance robots' inability to open doors. Leveraging user testing as a baseline, the program has derived time ranges necessary for military personnel to open doors with standard Unmanned Ground Vehicles (UGVs), and evaluates it's impact on overall mission duration, mission timing, and user patience in developing a safe and effective system. This program is funded through the US ARMY Tank and Armament Research arm (TARDEC) and represents a leap forward in perception, autonomy, and physical gripper interaction due to its real-world tactical relevance in door opening as well as continued robotic tasks. True tactical relevance is derived from the ability to provide high-speed ingress (as quickly as 30 seconds) and door configuration versatility (handles, knobs, varying swing direction, dual doors, sprung doors, and combinations).

The AURIS system has proven feasibility with semi-autonomous control and provides a feasible path for fully autonomous interior building reconnaissance. Through a novel gripping design, 3-dimensional vision capability, and elegant planned path execution, the AURIS system endeavors to provide a concept of operations that benefits many end users. It is designed to be implemented as an add-on kit to various common UGV platforms currently used by EOD, First Responder teams, and more.

A product of the combined experience of Boston Engineering Corporation's Advanced Systems Group (Waltham MA) and Autonomous Solutions Inc. (Petersboro UT), AURIS leverages their combined robotics, autonomy, mechatronics, software, sensing, and vehicle control experience.

8387-38, Session 9

Advanced dual-haptic manipulator system for CIED

D. R. Erickson, Defence Research and Development Canada, Suffield (Canada)

This paper outlines a Canadian project investigating improved EOD robot manipulators and immersive man-machine interfaces to enable the EOD technician to neutralize more threats remotely. The goal is to expand the manipulator capabilities so that more complicated manual dexterity operations can be remote.

This research will deliver an augmented remote-control vehicle telepresence system with immersive features including a 3D vision system and a haptic interface that conveys force information to the user including object compliance, terrain, and road condition so the operator can understand situation better. This augmented feedback has been shown to improve remote teleoperation. The developed vehicle dynamics model is expected to simulate model stability, road conditions, and traction forces on the vehicle movements. The vehicle will be equipped with two coordinated robotic arms employing joint-level torque control, haptics, and replaceable tool end-effectors allowing the user to remotely observe, sense, and react to the objects the robot is manipulating. The vehicle will have an end-effector tool change system, 3D vision system, cameras, and simultaneous localization and mapping (SLAM) algorithms employing scene reconstruction and mapping in real time.

8387-39, Session 9

Game theory applied to legged robotics: a variant of the dolichobrachistochrone problem

P. L. Muench, D. B. Bednarz, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

We model the scenario between a robotic system and its operating environment as a strategic game between two players. The problem will be formulated as a game of timing. We will treat disturbances in a worst case scenario, i.e., as if they were placed by an opponent acting optimally. Game theory is a formal way to analyze the interactions among a group of rational players who behave strategically. We believe that behavior in the presence of disturbances using games of timing will reduce to optimal control when the disturbance is suppressed.

In this paper we create a model of phase space similar to the dolichobrachistochrone problem of Isaacs. We discretize phase space to a simple grid where Player P is trying to reach a goal as fast as possible, i.e., with minimum cost. Player E is trying to maximize this cost. To do this, E has a limited number of "chips" to distribute on the grid. How should E distribute his resources and how should P navigate the grid? Rather than treating disturbances as a random occurence, we seek to treat them as an optimal strategy.

8387-40, Session 9

Detecting and learning of geometrically relevant features for legged locomotion

B. L. Digney, Defence Research and Development Canada, Suffield (Canada)

Previous publications reported on the learning of tractive and compressive terrain characteristics for the little dog quadruped robot. This paper will report on methods developed to classify terrain geometry into parametrized feature models of use to legged locomotion control systems. Specifically, for use by foot placement planning systems attempting to cross irregular terrains. Methods for detecting simple features such as slope direction and surface roughness to more complex step features such as step direction, sharpness and height will be presented. Additional work on developing parametrized models of foot grip/hold points for the point feet of little dog will be presented. The parameters of these models is set by the control software as foot hold quality is learned allowing increasingly better foot holds to be detected. It is intended that this coupling between experience based learning and feature detection will result in only eventually features that are known to be useful being noticed and presented for use to leg controllers. This method is similar to our previously presented work on learned trafficability but incorporates both exploratory terrain interaction and merit indices with complex terrain features. Rather than terrain appearance correlated with terrain flatness of learned trafficablity.

8387-41, Session 9

Improving UGV teleoperation performance using novel visualization techniques and manual interfaces

S. Vozar, D. Tilbury, Univ. of Michigan (United States)

Unmanned ground vehicles (UGVs) are well-suited to a variety of tasks that are dangerous or repetitive for humans to perform. Despite recent advances, UGVs still suffer from reliability issues, and human operation failures have been identified as one root cause of UGV system failure. However, most literature relevant to UGV reliability does not address the effects of human errors or the user interface. Our previous work investigated the issue of user situational awareness and sense of presence in the robot workspace by implementing a Mixed Reality interface featuring a first-person video feed with an Augmented Reality overlay and a third-person Virtual Reality display. The interface was evaluated in a series of user tests in which users manually controlled a UGV with a manipulator arm using traditional input modalities including a computer mouse, keyboard and gamepad. In this study, we learned that users found it challenging to mentally map commands from the manual inputs to the robot arm behavior. Also, switching between control modalities seemed to add to the cognitive load during teleoperation tasks. A master-slave style manual controller can provide an intuitive one-to-one mapping from user input to robot pose, and has the potential to improve both operator situational awareness for teleoperation tasks and decrease mission completion time. This paper describes the design and implementation of a teleoperated UGV with a Mixed Reality visualization interface and a master-slave controller that is suitable for teleoperated mobile manipulation tasks.

8387-42, Session 10

Autonomous exploration and mapping of unknown environments

J. L. Owens, U.S. Army Research Lab. (United States); P. R. Osteen, Motile Robotics Inc. (United States); M. Fields, E. Haas, U.S. Army Research Lab. (United States); K. Daniilidis, Univ. of Pennsylvania (United States)

Autonomous search and exploration is a vital capability for future robotic systems, which will be expected to function in arbitrary and complex environments. In this paper, we describe an end-to-end robotic solution for remotely exploring buildings for target objects of interest. In typical scenarios, an unmanned vehicle is directed to enter an unknown building at a distance, sense the internal structure while creating a 2- or 3-D map of the building, and search for objects of interest. The map provides a useful and intuitive representation of the environment for a remote operator and provides information on how to find the objects. We have integrated a robust mapping system utilizing laser range scanners and RGB-D cameras, and we demonstrate an exploration, object detection, and meta-cognition algorithm on a robotic platform.

The algorithm allows the robot to safely navigate to the building, explore the interior, report objects to the operator, and generate a consistent map-all while maintaining localization. The generated maps consist of both estimated 2-D floor plans with object positions and 3-D point clouds that can be visualized by an operator using a simple touch-screen interface on a remote tablet. Our system makes use of both in-house and community-developed algorithms for visual odometry, SLAM, path planning, exploration, object detection, and meta-cognition. To evaluate the system, we show results from three different building environments with varying conditions. In each location the robot must navigate to the building, discover an opening, explore, map and search the interior and return to the operator.

8387-43, Session 10

Development and test results of autonomous behaviors for urban environment exploration

G. Ahuja, D. Fellars, G. Kogut, E. Pacis Rius, A. Xydes, Space and Naval Warfare Systems Ctr. Pacific (United States)

Under the Urban Environment Exploration project, SSC Pacic is maturing technologies and sensor payloads that enable man-portable robots to operate autonomously within the challenging conditions of urban environments.

Previously, SSC Pacic has demonstrated robotic capabilities to navigate and localize without GPS and map the ground oors of various buildings sizes (Ahuja, et al. '09). SSC Pacic has since extended those capabilities to localize and map multiple stories of multiple buildings within a specied area. To facilitate this, SSC Pacic developed related technologies which enable the robot to nd stairs/stairwells, stay localized at all times (e.g.

in a 3D world, on stairs, with/without GPS), visualization of the data in 3D, path planning between any two points within the specied area, and psuedo-3D obstacle avoidance using a vertically mounted Hokuyo LIDAR. These technologies have been developed as independent behaviors under a behavior architecture called the Autonomous Capabilities Suite (ACS). These behaviors were then tested at a MOUT site in Camp Pendleton by measuring the performance of the system as well as individual behaviors. This paper describes the capabilities developed and their related ACS behaviors, the test procedures, and test results.

8387-44, Session 10

Development of an info-gap-based path planner to enable non-deterministic, low-observability mobile sensor nodes

D. L. Mascareñas, C. J. Stull, C. R. Farrar, Los Alamos National Lab. (United States)

Mobile sensor nodes are an ideal solution for efficiently collecting measurements for a variety of applications. Mobile sensor nodes exhibit a particular advantage when measurements must be made in hazardous and/or adversarial environments. When mobile sensor nodes must operate in hostile environments, it would be advantageous for them to be able to avoid undesired interactions with hostile elements. It is also of interest for the mobile sensor node to maintain low-observability in order to avoid detection by hostile elements. Conventional path-planning strategies typically attempt to plan a path by optimizing some performance metric. The problem with this approach in an adversarial environment is that it may be relatively simple for a hostile element to anticipate the mobile sensor node's actions (i.e. optimal paths are also often predictable paths). Such information could then be leveraged to exploit the mobile sensor node. Furthermore, dynamic adversarial environments are typically characterized by high-uncertainty and high-complexity that can make synthesizing low-observability paths very difficult. The goal of this work is to develop a path-planner anchored in info-gap decision theory, capable of generating non-deterministic paths that satisfy predetermined performance requirements in the face of uncertainty about the actions of the hostile element(s) and/or the environment.

8387-45, Session 10

Energy conservation for UGVs executing coverage tasks

J. Broderick, D. Tilbury, E. Atkins, Univ. of Michigan (United States)

Unmanned ground vehicles (UGVs) often operate in areas that are dangerous for humans to enter. If the batteries run out, the UGV risks becoming permanently immobilized - requiring humans to retrieve it from a dangerous area. Thus, proper management of the available on-board battery power is critical for reliable UGV operations. In this paper, we will focus on the task of area coverage - in which a UGV is asked to move through an area inspecting or searching for something - with limited available energy.

We examine coverage paths (sequences of waypoints) generated by exiting methods, and find trajectories that follow these paths using an optimal control formulation. Our novel cost function includes terms representing the force input necessary to drive the robot and the remaining currently uncovered region. Using this cost function, we compute an optimal traversal of the path by connecting the waypoints. Trade-offs between area covered versus the time and energy required are presented. A simple trajectory modification allows the vehicle to continue moving through a turn to further reduce energy consumption.

In the iRobot Packbot, battery state-of-charge and the motor currents can be measured during operation. GPS values can be used to track the robot position. In this paper, we describe how we can use these measured values to refine the cost function to more accurately represent the actual energy used and the actual area covered during an autonomous coverage operation. Simulation and experimental results will be presented.

8387-46, Session 11

Enabling unmanned capabilities in the tactical-wheeled vehicle fleet of the future

N. Zych, Oshkosh Corp. (United States)

From transporting troops and weapons systems to supplying beans, bullets, and Band-Aids to front-line warfighters, tactical wheeled vehicles serve as the materiel backbone anywhere there are boots on the ground. Drawing from the U.S. Army's Tactical Wheeled Vehicle Strategy and the Marine Corps Vision & Strategy 2025 reports, one may conclude that the services have modest expectations for the introduction of large unmanned ground systems into operational roles in the next 15 years. However, the Department of Defense has already invested considerably in the research and development of full-size UGVs - and commanders deployed in both Iraq and Afghanistan have advocated the urgent fielding of early incarnations of this technology, believing it could make a difference on their battlefields today.

For military UGVs to evolve from mere tactical advantages into strategic assets with developed doctrine, they must become as trustworthy as a well-trained warfighter in performing their assigned task. Starting with the Marine Corps' ongoing Cargo Unmanned Ground Vehicle program as a baseline, and informed by feedback from previously deployed subject matter experts, this paper examines the gaps which presently exist in UGVs from a mission-capable perspective. It then considers viable near-term technical solutions to meet today's functional requirements, as well as long-term development strategies to enable truly robust performance. With future conflicts expected to be characterized by increasingly complex operational environments and a broad spectrum of rapidly adapting threats, one of the largest challenges for unmanned ground systems will be the ability to exhibit agility in unpredictable circumstances.

8387-47, Session 11

ROBODEXS: multirobot deployment and extraction system

J. P. Gray, J. R. Mason, M. S. Patterson, M. W. Skalny, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

The importance of the implementation of Unmanned Ground Vehicles (UGV's) in the Military's operations is continually increasing. All Military branches now rely on advanced technology to aid in their missions' operations. The integration of these technologies has not only increased capabilities, but has increased personnel safety by generating larger standoff distances. Currently most UGV's are manually deployed because the Military possess a limited capability to do so remotely and can only deploy a single UGV.

This paper explains the conceptual development of a novel approach to remotely deploy and extract multiple UGV's. The Robotic Deployment and Extraction System (ROBODEXS) is a result of our development research to improve marsupial robotic deployment at safe standoff distances. The presented solution is modular and scalable, having the ability to deploy anywhere from two to twenty UGV's from a single deployment mechanism. For larger carrier platforms, multiple sets of ROBODEXS modules may be integrated for deployment and extraction of even greater numbers of UGV's. Such a system allows mass deployment and extraction from a single manned/unmanned vehicle, which is not currently possible with other deployment systems.

8387-48, Session 11

Dealing with unreliable and long latency communications in tactical and space robotic applications

D. W. Gage, XPM Technologies (United States)

Limited communications is often one of the key factors limiting the effectiveness of robots: poor communications reliability in tactical robot applications in urban terrain, extremely long communications latency in space applications, and inadequate bandwidth in both tactical and space applications, as well as many others. This paper presents an approach for dealing with long latency links between a quasi-autonomous robot and its controller, and then seeks to apply this approach more widely by treating intermittent link failures as a case of varying link latency. The approach implements predictive models reflecting a hierarchy of control abstractions working at different timescales. “Dynamic autonomy” results from operator intervention occurring at multiple levels, as appropriate.

8387-49, Session 11

Mesh networking optimized for robotic teleoperation

A. Hart, H. G. Nguyen, N. Pezeshkian, K. F. Holz, Space and Naval Warfare Systems Ctr. Pacific (United States)

Mesh networks for robotic teleoperation contrast significantly with traditional mesh networks. Specifically, unmanned ground vehicles (UGVs) have unique traffic requirements, their mobility creates a dynamic network condition, and they must work reliably in uncontrolled environments. Building a mesh network to perform in such conditions poses numerous questions. For example, will there be multiple robots on the same network? Will robots act as mesh nodes for other robots? How does the mesh know which route is most appropriate? How will a robot’s native network topology work with the mesh? SSC Pacific’s Manually Deployed Communication Relay (MDCR) system employs a unique mesh network that successfully overcomes these obstacles. This paper presents the modified Babel-based mesh network used by MDCR that allows multiple platform-independent UGVs to build and use a single mesh network. Based on data from qualitative performance metrics, we show how changes in mesh route selection can improve the robustness and effectiveness of a robotic mesh network. This paper summarizes MDCR System performance in urban, forested, and hilly environments and gives insights into how the operator should decide on mesh node placement.

8387-50, Session 11

Getting it right the first time: predicted performance guarantees from the analysis of emergent behavior in autonomous and semi-autonomous systems

R. C. Arkin, Georgia Institute of Technology (United States); D. M. Lyons, Fordham Univ. (United States)

Robots are currently deployed in Iraq and Afghanistan against conventional explosive threats, e.g., improvised explosive devices (IEDS) but without the use of any significant level of autonomy. WMDs, whether they by chemical, biological, or nuclear (CBN), obviously up the ante substantially and there is no tolerance for mistakes. Autonomy is increasingly demanded due to the large-scale hazard to human life and the need for a rapid response. However, to deploy autonomous systems effectively in such counter-WMD scenarios it is crucial to have a means of establishing performance guarantees for the systems.

The field of formal specification and verification of software systems has made impressive progress. However, leveraging these results to validate software for mobile robot systems has raised new challenges. In ongoing research for DTRA, we (1) introduce -a concurrent, communicating process-based formal model for describing behavior-based mobile robot programs, as well as the environments in which the programs operate, and (2) a robot program development toolkit for robot software validation and verification functionality.

The software development environment is embedded into the Missionlab software package, a comprehensive robot mission development, simulation and execution environment. Once the mission has been created, the designer can choose to validate the program’s behavior in a range of standard environments. The designer selects from a library of sensor and motor models that include a range of noise and uncertainty characteristics and can request the validation of the combination of robot program and environment for specific properties of safeness, liveness or efficiency.

8387-51, Session 11

Characteristics of a maritime-interdiction-operations, unmanned ground vehicle

H. G. Nguyen, M. Baker, Space and Naval Warfare Systems Ctr. Pacific (United States)

The U.S. Navy conducts thousands of Maritime Interdiction Operations (MIOs) every year around the globe. Navy Visit, Board, Search, and Seizure (VBSS) teams regularly board suspect ships and perform search operations, often in hostile environments. There is a need for a small throwable robot that can be deployed ahead of the team to provide enhanced situational awareness in these boarding, breaching, and clearing operations. We performed a market survey, identified, and obtained a number of small tactical robots that may be useful in these situations. Then we conducted user evaluations with Navy VBSS team members, taking each of these robots through every step of the VBSS operation in realistic training environments. From these tests, we extracted and defined the design parameters for an ideal MIO robot. This paper describes the tests conducted and the identified characteristics of this robot.

8387-52, Session 11

Design of a transformative spherical mobile robot

K. Hou, H. Sun, Q. Jia, Beijing Univ. of Posts and Telecommunications (China)

Spherical robot, as the novel mobile robot, has been studied by many scholars in recent years. A spherical robot is a kind of mobile robot which has a shape of ball and consists of driven mechanism and control system inside the spherical shells. This robot relies on the relocation of internal weight distribution or mass point for propulsion. Because of the character of flexible movement, spherical robot is suitable to be used in many circumstances, such as space exploration, environment monitoring, military reconnaissance. This paper presents a transformative spherical robot which has a shape-shifting shell. When the robot is not working, the whole robot looks like a normal cylinder; when the robot is working, it changes the shape of shells to make itself a ball to move. This robot has the character of concealment and long lasting time, and its height can be changed freely. The spherical robot has two parts: the spherical shell and the inner driven system. The spherical shell contains many spoke-like elastic materials. The elastic materials fix their both ends with the inner driven system. An actuator inside changes the length of the inner driven system to deform the shell, and this can realize the exchange of roles-a normal cylinder and a spherical robot. Two motors in the inner driven system can drive the spherical robot move in all direction. The mechanical structure and control system are introduced in detail. The key mechanical structure parameters are analyzed at length and the simulations of the robot’s move are provided to confirm the feasibility. The experimental results of the robot are shown in the final part.

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8388-01, Session 4

A fusion solution for soldier wearable gunfire detection systems

G. Cakiades, S. V. Desai, U.S. Army Armament Research, Development and Engineering Ctr. (United States); S. Deligeorges, BioMimetic Systems, Inc. (United States)

No abstract available

8388-02, Session 4

Examination of techniques utilized to evaluate muzzle suppression systems

D. Grasing, U.S. Army Research, Development and Engineering Command (United States); S. V. Desai, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8388-03, Session 5

Unattended ground sensors (UGS) and ultra-wideband (UWB) technologies: a perfect match

P. Proietti, SELEX Sistemi Integrati S.p.A. (Italy); A. Centuori, CMC Labs. (Italy); L. Di Donato, S. Mattiacci, SELEX Sistemi Integrati S.p.A. (Italy)

Low complexity, low power sensors with simple communication techniques are a forced system's choice for small and stealthy UGS.

Currently, different wireless communication standards are available, such as Bluetooth, Wi-Fi or Zigbee, but those are either too power-consuming, too complex, too expensive or limited in the number of nodes.

In contrast, impulse radio ultra-wideband (IR-UWB) communication is recognized to be scalable and able to be integrated into WSN.

UWB technology has the potential to achieve long operation range, low-power consumption with low-complexity transceivers, capabilities to support high data rate communications, to guarantee high precision localization and to detect movements under non-line-of-sight conditions.

IEEE 802.15.4a study group has already delivered a standard specification for UWB-based sensor networks.

Selex S.I. and CMC Labs are studying how to implement a smart UGS system based on modern UWB technology with cognitive radio concepts for flexible frequency usage, which can sense and characterize the surrounding radio wireless environment and can be integrated with an existing telecommunication infrastructure, permitting an intelligent use of the available spectrum and energy resources. Moreover it can be envisioned as an important component for local high data-rate extensions of military systems and WSN peripheral, holding significant potentials to serve as covert communications solution with low probability of detection (LPD).

The spectral and power efficiency feature of UGS based on UWB radio will meet the most demanding requirements on the field of operations, balancing the energy budget and therefore improving the operational life of the WSN technologies.

8388-04, Session 5

Near sea surface 1.55 µm free-space optical communication links through the evaporation layer

J. W. Zeller, T. Manzur, Naval Undersea Warfare Ctr. (United States)

No abstract available

8388-06, Session 6

Vision navigation for UAV based on scene matching

Y. Shang, X. Li, W. Hou, X. Liu, X. Zhu, X. Yang, Q. Yu, H. Zhang, National Univ. of Defense Technology (China)

As a rising navigation technology, vision navigation has many advantages, such as passive mesurement, anti-interference, no-accumulation of error and comprehensive parameters, etc. It shows a promising application prospects in autonomous navigation for UAV.

Based on an efficient, reliable and accurate scene matching, three UAV navigation methods using the aerial image sequences are proposed.

The first method measures UAV's velocity by tracking ground features between image sequences, assisted with height measurement.

The second registers aerial images with reference images, then, calculates UAV's position with the attitude from INS. It can measure UAV's speed and heading by data filtering.

The third matches multiple points between aerial image and reference image, and estimates UAV's position and attitude according to photogrammetry. UAV's velocity and palstance can be estimated by sequence images.

All three methods have been validated in flight tests.

8388-07, Session 6

Small form-factor ultraviolet laser source

R. Olah, Banpil Photonics, Inc. (United States)

No abstract available

8388-08, Session 6

Passive sky angle mapping for unmanned ground vehicles

R. Grabowski, The MITRE Corp. (United States)

No abstract available

8388-09, Session 7

The DARPA HUMS Program: revolutionizing magnetic field sensors using multiferroic materials and atomic gas vapor cells

W. Coblenz, Defense Advanced Research Projects Agency (United States); S. Wartenberg, Booz Allen Hamilton Inc. (United States)

No abstract available

8388-10, Session 8

MAGID-II: a next-generation magnetic, unattended ground sensor

P. A. Walter, P. Huber, F. Mauriello, L-3 Communication Systems-East (United States)

A next generation magnetic sensor is being developed at L-3 Communications, Communication Systems East to enhance the ability of Army and Marine Corps unattended ground sensor (UGS) systems to detect and track targets on the battlefield. This paper describes a magnetic sensor that provides superior detection range for both armed personnel and vehicle targets, at a reduced size, weight, and level of power consumption (SWAP) over currently available magnetic sensors. The design integrates the proven technology of a flux gate magnetometer combined with advanced digital signal processing algorithms to provide the warfighter with a rapidly deployable, extremely low false-alarm-rate sensor. This new sensor improves on currently available magnetic UGS systems by providing not only target detection and direction information, but also a magnetic disturbance readout, indicating the size of the target. The sensor integrates with Government Off-the-Shelf (GOTS) systems such as the United States Army's Battlefield Anti-Intrusion System (BAIS) and the United States Marine Corps Tactical Remote Sensor System (TRSS). The system has undergone testing by the US Marine Corps, as well as extensive company testing. Results from these field tests are given.

8388-11, Session 8

Application of nods with multiple orthogonal sensors in moving light vehicles study

A. E. Ekimov, The Univ. of Mississippi (United States)

A sensor node having two types of sensors: sound and seismic units was used for signal collection in a test with different moving light vehicles on a gravel road in a quiet area. An analysis of signals from the node at low frequencies shows the possibility of detecting a vehicle at a distance almost one half of a mile away. The microphone (sound) signals for the vehicle motion were detected above the lowest frequencies of 15-20 Hz only while the geophone signals had the maxima in that frequency band. Another test was conducted on the ground with the goal of finding the common vibrations of a light vehicle and the ground due to vehicle passby in the low frequency range. For this signal collection another sensor node with ten orthogonal sensors was used. This node had co-located passive and active sensors. An additional 3-x accelerometer was installed in the vehicle cabin above the transmission. For start time synchronization of recorded signals from the node on the ground and 3-x accelerometer in the vehicle cabin a radio channel was used. Results for this test revealed the vehicle vibrations due to motion in the low frequency range were detected on the ground with all three components of the 3-axes geophone only for the entire distance. This vehicle's vibrations in the low frequency range were detected with the accelerometer inside of the vehicle also. This work was supported by the US Army Armament Research, Development, and Engineering Center under contract W15QKN-09-C-0163.

8388-12, Session 8

Ultrasonic bistatic Doppler sonar in air for personnel motion detection

A. E. Ekimov, C. Hickey, The Univ. of Mississippi (United States)

The National Center for Physical Acoustics at the University of Mississippi is working on the application of ultrasonic Doppler sonars in air for personnel motion detection. Two traditional Doppler sonar configurations, a monostatic and a bistatic configuration, are being studied. In the monostatic configuration the distance between the transmitter and the receiver is small. The proximity of the source to the receiver places a limitation on the system associated with the overloading of the receivers' input due to acoustic energy leakage from the transmitters' output. The maximum range of detection is therefore limited by the dynamic range of the acquisition system. In bistatic Doppler ultrasonic sonar, the source and receiver are spaced apart and the acoustic energy along the direct path does not constrain the maximum acoustic power level output of the transmitter. In a monostatic configuration the acoustic signal suffers from beam spreading and natural absorption during propagation from the transmitter to the target and from the target back to the receiver. In a bistatic configuration the acoustic propagation is in one direction only and theoretically the detection distance can be twice the monostatic distance. Experiments measurements of a human walking in a building hallway using bistatic Doppler sonar in air are conducted. The experimental results for human signatures from a bistatic ultrasonic Doppler sonar are presented and discussed.

8388-13, Session 8

Corner-cube retroreflector chemical sensors based on MEMS

P. G. C. Datskos, Oak Ridge National Lab. (United States)

No abstract available

8388-14, Session 9

Spatial voting with data modeling for behavior-based tracking and discrimination of human from fauna from GMTI radar tracks

H. M. Jaenisch, Licht Strahl Engineering, Inc. (United States) and The Johns Hopkins Univ. (United States); J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We introduce a novel method of using ground track indicators in conjunction with our Spatial Voting algorithm and data fusing Data Models to distinguish target types from motion signatures alone. Our method creates a novel pixel map from the stacked grid landscape derived from Spatial Voting and aggregation of track reports. Statistical Heptor based characterization is used to create predictive identifying models of the varying pixel fields to recognize consistent behavior and then also become features for deriving a classifier for target identification. We show our methods and results.

8388-15, Session 9

Optimizing the configuration patterns for heterogeneous distributed sensor fields

T. A. Wettergren, R. Costa, Naval Undersea Warfare Ctr. (United States)

When unmanned distributed sensor fields are developed for rapid deployment in hostile areas, the deployment may consist of multiple

sensor types. This occurs because of the variations in expected threats and uncertainties about the details of the local environmental conditions. As more detailed information is available at deployment, the quantity and types of sensors are given and fixed, yet the specific pattern for the configuration of their deployment is still variable. We develop a new optimization approach for planning these configurations for this resource constrained sensor application. Our approach that takes into account the variety of sensors available and their respective expected performance in the environment, as well as the target uncertainty. Due to the large dimensionality of the design space for this unmanned sensor planning problem, heuristic-based optimizations will provide very sub-optimal solutions and gradient-based methods lack a good quality initialization. Instead, we utilize a robust optimization procedure that combines genetic algorithms with nonlinear programming techniques to create numerical solutions for determining the optimal spatial distribution of sensing effort for each type of sensor. We illustrate the effectiveness of the approach on numerical examples, and also illustrate the qualitative difference in the optimal patterns as a function of the relative numbers of available sensors of each type. We conclude by using the optimization results to discuss the benefits of interspersing the different sensor types, as opposed to creating area sub-segmentations for each type.

8388-16, Session 9

Space-time statistical models for inhomogeneous acoustic propagation environments

J. N. Ash, The Ohio State Univ. (United States)

When acoustic signals are subject to measurement over large distances or extended periods of time, the environmental conditions governing their propagation are unlikely to remain constant over the necessary spatial and temporal extents. Relative to a static environment, such inhomogeneities may result in severe signal distortion, such as non-linear warping, and can significantly degrade subsequent signal processing tasks like classification or time-delay estimation.

In this paper we 1) describe a set of experiments that were performed in order to collect space-time acoustic propagation data for empirical modeling, paying particular attention to important experimental design issues such as Nyquist sampling rates in the spatial domain, and 2) present a statistical two-dimensional model for inhomogeneous environments that describes the space-time distribution of acoustic propagation velocity and first order components such as temperature and wind velocity. The model includes a deterministic component to model structured changes (e.g., increasing temperature during morning hours) and a stochastic component, specified by a two dimensional Gaussian random process, to capture correlated random deviations. An example application to time-delay estimation demonstrates how the model may be used to imbue signal processing applications with awareness and robustness to inhomogeneous conditions.

8388-17, Session 10

Pearls of wisdom: wireless networks of miniaturized unattended ground sensors

B. Rippin, Pearls of Wisdom (Israel)

Pearls of Wisdom has been working on the development of sensing systems for unattended ground applications using miniaturized elements. Our vision is to enable various monitoring applications using the deployment of a large number of low cost miniature wireless sensors. The operation of sensors of multiple modalities working in harmony, together with the ability to integrate the measurements and turn them into coherent information provides an opportunity for new applications and improved performance. The development of such systems is based on three pillars of excellence: a wireless network foundation which is low bandwidth, yet flexible enough to support the needs of different applications, ultra-low-power design of sensors and a distributed data analysis system. Miniaturization and dense deployment of sensors enable the usage of a variety of “time/space” analysis methods for multi-sensor processing. These algorithms provide improved probability of detection at a lower false alarms rate, especially in rough terrain and vegetation. We describe an application of human tracking using a mixture of acoustic sensors and daylight still cameras. The close integration between the acoustic and visual modalities resulted in the camera activation at the proper time and location only. This configuration enables efficient usage of camera sensor power. Further, the network transmits only those images which are consistent with the acoustically generated tracks, providing a very high hit rate for relevant and informative images.

8388-18, Session 10

Dynamically reconfigurable, multivariable MEMS sensor array for unattended systems

S. P. van der Velden, I. G. Powlesland, S. C. Galea, Defence Science and Technology Organisation (Australia); J. Singh, La Trobe Univ. (Australia)

Unattended systems by their very nature need to be robust; and it is highly desirable that they be adaptable to a dynamically changing environment. Within a research program investigating structural health monitoring systems for uninhabited aerial vehicles, conducted at the Defence Science and Technology Organisation in conjunction with La Trobe University, is an investigation into MEMS sensors for such systems.

This paper presents a dynamically reconfigurable multivariable MEMS sensor array, capable of reconfiguration in real time, to meet the demands of an ever changing environment, with an emphasis on maintaining operation in the presence of damage. This array is comprised of multiple instances of identical sensors, which can be dynamically reconfigured to achieve the desired measurand(s).

Presented in this paper is a MEMS structure capable of measuring several different physical phenomena, such as, accelerations, rotational rates, magnetic fields, temperature, air pressure and density; depending on how it is currently configured. Simulations of some of these measurands are presented, along with details of dynamic reconfiguration from one measurand to another. Also shown are some simulations that demonstrate the ability of such a sensor array to continue operation in the presence of damage, and hence enable graceful degradation of the system.

8388-19, Session 10

Radiation detection and wireless networked early warning

D. A. Burns, M. S. Litz, D. Katsis, J. J. Carroll, U.S. Army Research Lab. (United States)

We have designed a compact, wireless, GPS-enabled array of radiation sensors based on scintillation counting. The system is designed around the priorities of inexpensive, wireless-network, and sensitivity. Each sensor has a scintillator, photomultiplier tube, and pulse counting circuit controlled by an Atmel microprocessor. A comparator is controlled by a digital potentiometer that provides a high level of sensitivity and reliability. A 0.2 m2 PV panel powers each sensor providing a maintenance-free 24/7 energy source. The sensor can mount within a roadway light-post and monitor radiological activity along transport routes. Each sensor wirelessly transmits real-time data (as counts per second) using its own XBee long-range-module. The transmitted data is received by a XBee receive-module on a computer. Data collection software logs the information from all sensors and provides real-time identification of radiation events. Additionally, software gives real-time event-analysis including time-tracking of sources at each sensor, activity at each sensor location as a function of time, and overlaying of on-board-GPS data with Google maps. Measurements performed to-date demonstrate the ability of a sensor to detect a 20 µCi source at 3.5 meters when packaged with a PVT (plastic) scintillator, and 7 meters in a sensor with a CsI crystal (more expensive but ~5 times more sensitive). The 20 μCi gamma source was detected while moving 88 km/h, showing speed of the sensor controller is not an impediment to transport route use. It is calculated that the sensor-architecture can detect sources moving as fast as 130 km/h based on the current data rate and statistical bounds of 3-sigma threshold detection. The sensor array is suitable for identifying and tracking a radiation threat from a dirty bomb along roadways.

8388-20, Session 10

Seismic and ultrasonic data analysis for characterizing people and animals

T. Damarla, U.S. Army Research Lab. (United States)

In this paper we analyze the seismic signals generated by the people and animals walking. It is known that when a person walks, the heel strikes first and then the front of the foot; whereas animals walk on their hoofs. This difference in the walking patters result is significant changes in the seismic signatures for both people and animals. Similarly, men walk differently than women and they also have different weight distributions resulting in different signatures for men and women. They also have different cadence or gait patterns. We distinguish the significant features in seismic signatures to distinguish women, men and animals. Ultrasonic Doppler returns capture the variations in the gait. The Doppler returns will be analyzed to distinguish people and animals. Algorithms to classify the signatures will be provided. The algorithms will be tested on the data collected at a horse farm with women, men and people walking. The results will be discussed along with possible future research directions to reduce the number of false alarms.

8388-21, Session 10

Automatic human action recognition in a scene from visual inputs

H. Bouma, P. Hanckmann, J. Marck, L. Penning, R. den Hollander, J. ten Hove, S. P. van den Broek, K. Schutte, G. Burghouts, TNO Defence, Security and Safety (Netherlands)

Ground surveillance is normally performed by humans, since it requires visual intelligence. However, it may be time consuming for many surveillance applications and even dangerous and harmful for military applications. Therefore, unmanned visual-intelligence systems are desired. In this paper, we present a novel system that can recognize and reason about the verbs (and the related nouns), enabling a more complete description of actions. Our system is inspired by human intelligence and it uses world knowledge to gain visual evidence and support decisions. The central element in our system is to break down high-level perceptual concepts to simpler and reusable observable cues. These cues allow us to reason over the actions with several methods, including a manually generated rule-based expert system and an automatically trained classification system.

The system is trained on 3482 videos and after training it is evaluated on 2589 videos (both provided by the Mind's Eye program of DARPA). A ground truth based on human annotations contains information about the presence or absence of 48 verbs for each video.

We compared our systems response to the manual annotations. Of several systems we evaluated, our rule-based expert system generalizes best and our automatic classification system, although it was slightly overtrained, reaches a good performance approaching human average response for many verbs.

8388-22, Session 10

Multisensor system for the protection of critical infrastructure of a seaport

M. Kastek, R. Dulski, M. Zyczkowski, M. Szustakowski, P. Trzaskawka, W. Ciurapinski, Military Univ. of Technology (Poland); G. Grelowska, I. Gloza, S. Milewski, K. Listewnik, Polish Naval Academy (Poland)

There are many separated infrastructural objects within a harbor area that may be considered "critical", such as gas and oil terminals or anchored naval vessels. Those objects require special protection, including security systems capable of monitoring both surface and underwater areas, because an intrusion into the protected area may be attempted using small surface vehicles (boats, kayaks, rafts, floating devices with weapons and explosives) as well as underwater ones (manned or unmanned submarines, scuba divers). The paper will present the concept of multisensor security system for a harbor protection, capable of complex monitoring of selected critical objects within the protected area. The proposed system consists of a command centre and several different sensors deployed in key areas, providing effective protection from land and sea, with special attention focused on the monitoring of underwater zone. The initial project of such systems will be presented, its configuration and initial tests of the selected components. The protection of surface area is based on medium-range radar and LLTV and infrared cameras. Underwater zone will be monitored by a sonar and acoustic and magnetic barriers, connected into an integrated monitoring system. Theoretical analyses concerning the detection of fast, small surface objects (such as RIB boats) by a camera system and real test results in various weather conditions will also be presented.

8388-23, Session 10

Investigation of novel spectral and wavelet statistics for UGS-based intrusion detection

R. Narayanaswami, A. Gandhe, A. Tyurina, R. K. Mehra, Scientific Systems Co., Inc. (United States)

Customs and border patrol need a low cost reliable automated system to detect illegal border crossings across the Southern and Northern borders of the United States. Seismic Unattended Ground Sensors (UGS) are low cost and covert, making them a suitable candidate for border patrol. However, current seismic UGS systems use cadence-based intrusion detection algorithms and are easily confused between humans and animals. The poor discrimination ability between humans and animals results in missed detections as well as higher false alarm rates. False alarms reduce the trustworthiness of the system and lead to unnecessary actions, which may be costly. In order for seismic UGS systems to be deployed successfully, new signal processing algorithms with better discrimination ability between humans and animals are needed. We have identified that foot contact characteristics have a significant impact on the time-frequency characterization of recorded seismic signals. Following this discovery, we have characterized the seismic signals using frequency domain (spectral) and time-frequency domain (wavelet) statistics. A tree-based classifier was successfully implemented to discriminate among humans, animals (horses, cows, etc.) and vehicles. Kurtosis, a measure of skewness of a distribution, helps differentiate between an event and background. High frequency content is captured well by spectral shape statistics and frequency domain entropy measures. Vehicles are characterized by a higher proportion of energy at low frequencies captured well by wavelet statistics. Cadence is still useful in distinguishing small animal movement (rabbits and rats) form human walkers. However, cadence should not be used as the primary discriminator.

8388-24, Session 10

The Android smartphone as an inexpensive ground sensor

N. C. Rowe, R. Schwamm, Naval Postgraduate School (United States)

A key challenge of sentry and monitoring duties is detection of approaching people. We are exploring smartphones as easily available, easily portable, and less expensive ($100) alternatives to traditional military sensors for this task, where the sensors are already integrated into the package. We developed an application program for the Android smartphone that uses its sensors to detect people passing nearby; it takes their pictures for subsequent transmission to a central monitoring station. We experimented with the microphone, light sensor, vibration sensor, proximity sensor, orientation senesor, and magnetic sensor of the Android. We got best results with the microphone (looking for footsteps) and light sensor (looking for abrupt changes in light), and sometimes good results with the vibration sensor. We ran a variety of tests with subjects walking at various distances from the phone under different environmental conditions to measure limits on acceptable detection. We got best results by combining average loudness over a 200 millisecond period with a brightness threshold adjusted to the background brightness, and we set our phones to trigger pictures no more than twice a second.

Subjects needed to be within ten feet of the phone for reliable triggering, and some surfaces gave poorer results. We tested using the Motorola Atrix 4G (Android 2.3.4) and HTC Evo 4G (Android 2.3.3) and found definite differences in performance running the same program, which we attribute to differences in the sensor hardware.

Our results provide good guidance for when and where to use this approach to inexpensive sensing.

8388-25, Session 10

Fully integrated, automated security surveillance system: managing a changing world through managed technology and product applications

G. Francisco, DRS RSTA, Inc. (United States)

Integrated security systems are essential to pre-empting criminal assaults. Nearly 500,000 sites have been identified (source: US DHS) as critical infrastructure sites that would suffer severe damage if a security breach should occur. One major breach in any of 123 U.S. facilities, identified as “most critical”, threatens more than 1,000,000 people. The vulnerabilities of critical infrastructure are expected to continue and even heighten over the coming years.

Complete security confidence at these sites is still lacking due to shortcomings in over 12 critical security surveillance system capabilities.

Visible, night vision or near infrared imaging technology has limited viewing capability. Systems today yield excessive false alarms, staffed by fatigued operators unable to manage the data, and are lacking the ability to pinpoint an intrusion or worse, accurately assess the level of appropriate response.

This paper presentation describes surveillance installations using total security surveillance system solutions that incorporate long wave thermal camera technologies as well as intelligent video analytics in three specific areas:

- Thermal imaging technologies and inherent advantages/limitations of each, which are individually critical to successful forensic and proactive risk mitigation.

- Previous barriers, total cost of ownership considerations, warranty and product replacement requirements.

- Advantages of features such as IP readiness, Power-over-Ethernet (PoE), importance of standards (in interfacing software architecture, certification and test), cost size/weight/power, video analytics and future product growth development road-map requirements that assure successful risk mitigation.

Therefore, to have the highest confidence in a system that protects the public and assets to the fullest degree, an automated surveillance and software system is considered a highly valuable addition to current security systems.

Conference 8389: Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR III

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8389-01, Session 1

Ground/air multisensor interoperability, integration, and networking for persistent ISR: Introduction

T. Pham, U.S. Army Research Lab. (United States)

No abstract available

8389-02, Session 1

Data-to-decisions: a transdisciplinary approach to decision support efforts at ARL

B. D. Broome, U.S. Army Research Lab. (United States)

No abstract available

8389-03, Session 1

Toward data-to-decision sensing environments to assess human intent from responses to stimuli

C. Kothari, D. J. Russomanno, Indiana Univ.-Purdue Univ. Indianapolis (United States)

Automated detection of harmful intent via the analysis of human responses to external stimuli is crucial in many situation-assessment scenarios for defense and homeland security applications. Given the complexity of human behavior, imposing constraints on the sensed environment, including limits on the human responses and corresponding features that can be sensed and reasoned about, is critical to implementing pragmatic and effective decision-support tools. This paper overviews the challenges of developing data-to-decision frameworks to estimate the likelihood of harmful intent via human responses to stimuli within a heterogeneous and networked sensing environment. The approach leverages synthesized environments which are more likely to provide relevant features that can be used to infer intent. A Semantic Web compatible ontological framework is used to characterize key concepts and to provide a possible conceptual framework for subsequent design and implementation.

8389-04, Session 1

Tasking and sharing sensing assets using controlled natural language

A. Preece, D. Pizzocaro, Cardiff Univ. (United Kingdom); D. Braines, D. Mott, IBM United Kingdom Ltd. (United Kingdom)

We introduce an approach to representing intelligence, surveillance, and reconnaissance (ISR) tasks at a relatively high level in controlled natural language. We demonstrate that this facilitates both human interpretation and machine processing of tasks. More specifically, it allows the automatic assignment of sensing assets to tasks, and the informed sharing of tasks between collaborating users in a coalition environment. To enable automatic matching of sensor types to tasks, we created a machine-processable knowledge representation based on the Military Missions and Means Framework (MMF), and implemented a semantic reasoner to match task types to sensor types. We combined this mechanism with a sensor-task allocation procedure based on a well-known distributed protocol for resource allocation. In this paper, we re-formulate the MMF ontology in Controlled English (CE), a type of controlled natural language designed to be readable by a native English speaker whilst representing information in a structured, unambiguous form. We show how CE can be used to describe both ISR tasks (for example, detection, localization, or identification of particular kinds of object) and sensing assets (for example, acoustic, visual, or seismic sensors, mounted on motes or unmanned vehicles). We show how these representations enable an automatic sensor-task allocation process. Where a group of users are cooperating in a coalition, we show how CE task summaries give users in the field a high-level picture of ISR coverage of an area of interest. This allows them to make efficient use of sensing resources by sharing tasks.

8389-05, Session 1

Dynamic management of layered ISR systems

G. Pearson, Defence Science and Technology Lab. (United Kingdom)

No abstract available

8389-06, Session 1

Distributed network application and framework for quality of information processing

K. Marcus, L. M. Scott, T. J. Cook, A. Toth, U.S. Army Research Lab. (United States)

To improve the effectiveness of network-centric decision making, we present a distributed network application and framework that provides users with actionable intelligence reports to support counter insurgency operations. ARL's Quality of Information (QoI) Intelligence Report Application uses QoI metrics like timeliness, accuracy, and precision combined with associated network performance data, such as throughput and latency, and mission-specific information requirements to deliver high quality data to users; that is data delivered in a manner which best supports the ability to make more informed decisions as it relates to the current mission. This application serves as a testing platform for integrated experimentation and validation of QoI processing techniques and methodologies. In this paper, we present the software-system framework and architecture, and show example scenarios which highlight how the framework aids in network integration and enables better data-to-decision.

8389-07, Session 1

A system architecture for exploiting mission information requirement and resource allocation

F. Chen, T. La Porta, The Pennsylvania State Univ. (United States); D. Pizzocaro, A. Preece, Cardiff Univ. (United Kingdom); M. B. Srivastava, Univ. of California, Los Angeles (United States)

No abstract available

8389-08, Session 2

Unattended ground sensors standards working group: focus on software architecture, wired/wireless interfaces, and user interfaces

R. Heathcock, U.S. Defense Intelligence Agency (United States); C. Brasch, The MITRE Corp. (United States)

The Unattended Ground Sensors Standards Working Group, working under the direction of the Department of Defense, has confirmed the direction of its three initial Technical Focus Groups (TFG). The Software Architecture TFG, led by the Army Research Laboratory (ARL), will focus on UGS systems controllers and component plug-ins, while developing a flexible architecture that adjusts to mission needs.The Wired/Wireless Interfaces TFG, led by the Marines, will identify standards for communications interfaces between system components. The User Interface TFG, led by Special Operations Command, will address user interfaces, such as data output, data dissemination, command and control, and emplacement.

8389-09, Session 2

Technology focus group efforts within the UGS standardization working group

J. Houser, U.S. Army Research Lab. (United States)

The Unattended Ground Sensors (UGS) Standardization Working Group (SWG) is identifying standards and methods to achieve interoperability. The UGS SWG organization includes Technology Focus Groups (TFGs) which address specific issues and submit proposed technical solutions for consideration by the UGS SWG. This paper will describe the current TFGs, their efforts, membership, and near term goals.

8389-10, Session 2

Unattended sensors community of practice (USCOP)

P. Helt, Under Secretary of Defense for Intelligence (United States)

No abstract available

8389-11, Session 2

Standards-based sensor interoperability and networking

T. Countryman, Defense Intelligence Agency (United States)

Due to the on-going Community need for sharing sensor data within and across communities, it is critical that techniques be used and processes be built to facilitate informafiom assurance, data harmony, collection and missoon planning, and real-time tipping, cueing, and disseminatimg. To ensure sensors between separate communities and programs are able to share data, standards-based techniques and processes are being developed and promulgated that will assist user discovery and access.

8389-12, Session 2

Army's common operating environment (COE) sensor compute environment (CE) overview

C. E. Guthrie, U. S. Army (United States)

Sensor Computing Environment (CE): Provides a common interoperability layer, implementing Standards and technology(Services) for data services, network awareness, and security for specialized, human-controlled or unattended sensors and sensor systems.

8389-13, Session 2

Government and industry collaborative approach toward UGS interoperability

M. A. Kolodny, J. Houser, U.S. Army Research Lab. (United States)

No abstract available

8389-14, Session 3

Multisensor interoperability for persistent surveillance and FOB protection with multiple technologies during the TNT exercise at Camp Roberts, California

J. L. Chambers, Northrop Grumman-Xetron (United States); N. N. Murarka, Northrop Grumman Electronic Systems (United States)

Multiple sensors often have difficulty interoperating with each other to provide actionable intelligence to the war fighter. Northrop Grumman (NG) is dedicated to solving these problems to provide complete solutions for persistent surveillance. NG was invited to participate in the Tactical Network Topology (TNT) Capabilities Based Experimentation at Camp Roberts, CA in August, 2011, to demonstrate integrated system capabilities to provide Forward Operating Base (FOB) protection. This experiment was an opportunity to leverage previous efforts from NG's Rotorcraft Avionics Innovation Laboratory (RAIL) to integrate five prime systems of widely different capability. The five systems included a Hostile Fire and Missile Warning Sensor System, Scorpion II Unattended Ground Sensor system, Smart Integrated Vehicle Area Network (SiVAN), STARLite Synthetic Aperture Radar (SAR)/Ground Moving Target Indications (GMTI) radar system, and a vehicle with Target Location Module (TLM) and Laser Designation Module (LDM). These systems were integrated with each other and a Tactical Operations Center (TOC) equipped with RaptorX and Falconview providing a Common Operational Picture (COP) via Cursor on Target (CoT) messages. This paper will discuss this exercise and lessons learned by integrating these five prime systems for persistent surveillance and FOB protection.

8389-15, Session 3

ITA/CWP and ICB technology demonstrator: a practical integration of disparate ISR/ISTAR assets and technologies

F. Bergamaschi, IBM United Kingdom Ltd. (United Kingdom)

This paper will present the practical results of the combined ITA and ICB technologies in a recent field trial at Camp Roberts, CA, to assemble a coalition network in support to a Data-to-Decision (D2D) system which included the sharing and dissemination of sensor data and fused information, commanding and controlling two unmanned aerial vehicles (UAV) to harvest data from a sparse network of unattended ground sensors and collection of imagery from sites of interest.

A team of researchers from IBM UK, Teledyne Scientific Company, University of California at Santa Barbara (UCSB), the Army Research Laboratory (ARL), the Army Engineer Research and Development Center (ERDC) and Toyon Research Corporation collaborated in integrating ARL's Sensor Assets and the ITA Information Fabric (the Fabric) with the ICB's Autonomous UAV Persistent Surveillance using Bio-Inspired Strategies and Toyon's unmanned aerial vehicles (UAV).

The Information Fabric is a flexible and extensible middleware infrastructure that provides a unified framework for sensor identification and discovery, sensor access and control, and sensor data consumability. The Policy Management Toolkit consists of a set of flexible and extensible software modules that were developed to perform a variety of management functions on sets of policies applicable to sensors, sensor platforms, and networks. The Fabric was used to seamless integrate and disseminate data ARL's Acoustic sensor arrays in support of D2D applications.

ICB's Bio-inspired techniques for autonomous search provide a novel strategy to detect, capture and fuse data. The bio-inspired algorithm developed by UCSB is based on Chemotaxis or the motion of bacteria seeking nutrients in their environment, and it is used to generate data-driven autonomous collection routes and direct the UAVs to collect data from a sparse network of unattended ground sensors (UGSs).

The challenge was to integrate the previously unseen data flows from the UCSB algorithms into the Fabric such that they could be visualized in the Fabric Control station, and to send UCSB extra data from the ARL sensors to incorporate into their processing. A second integration was then to utilize either or both results to task the UAV appropriately.

The end result was a powerful technology demonstration at many levels that demonstrated that the Fabric is a viable solution for supporting Data-to-Decision-to-Action. The actual physical integration of multiple differing assets types in a short timescale shows that a common messaging infrastructure is a viable solution. The resulting demonstration of live UAVs capturing events and being tasked by separate ground based sensors automatically is a good asset in itself, and the sensor data gathered can now be re-used for simulation and repeat demonstrations as required.

8389-16, Session 3

An open and flexible interface proposal and proof-of-concept implementation to support service-orientated architectures and interoperability in the tactical environment

N. Peach, PB Partnership Ltd. (United Kingdom)

The development of Service Orientated Architectures (SOA) in the tactical domain has been hindered by a lack of interface standards suitable for the environment of unpredictable and low bandwidth communications, low powered computers and dynamic ad-hoc grouping of tactical participants. Existing commercial SOA standards have assumed reliable access to central servers and services and having relatively static participants.

The proposal describes an open and published message-oriented interface created to support the aims of the upcoming UK MoD Generic Base Architecture (GBA) Defence Standard and the associated Land Open Systems Architecture. The aims are; a) to support multiple open transport protocols, such as DDS and MQTT; b) to be suitable for integrating utility functions together with their controlling systems (such as water, waste and power) and integrating together high-level mission-support functions (such as ISTAR and C2); c) reduce operator burden by using automated discovery and configuration where possible; d) dynamically integrate with MoD Generic Vehicle Architecture platforms to link base and vehicle mission and logistics systems over tactical radio links; e) extensible to support features such as security classification; f) to be lightweight in implementation and bandwidth and not dependent on central servers for operation.

The paper will present the proposed interface and describe the features required for a military tactical, rather than a commercial environment, and will report the outcome of a MoD-funded trial of a lightweight Service Registry that first uses the proposed interface to interoperate several military systems.

8389-17, Session 3

A services-oriented architecture for deployable force protection

G. J. Miller, G. Mayott, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

It is becoming more common for tactical small units to operate in a decentralized, non-contiguous battle space environment while conducting decisive missions such as the prevention of disruption of critical infrastructure in a village. These missions are critical elements of returning the villages to complete government control and restoring the people's confidence in its local government. However, these missions often put the Soldier in a hostile environment without the protection assets afforded at a larger Forward Operation Base (FOB).

In support of these types of operations the advent of quick reaction procurement of systems and sensors has highlighted the need for common presentation of the Common Operating Picture (COP), common implementation of System Design (system of systems) to enable scalability (in support of both mission and equipment portability) and common definition of Information Exchange standards to enable interoperability. To date there have been multiple solutions that have provided limited interoperability across mission domains and with other QRC systems. While some current solutions offer a common architecture that exhibits net-centric features, these type systems are typically vendor-specific in design, data format, and interfaces. As a result, interoperability among sensors and between sensors and Mission Command systems is severely limited. This results in a significant reduction in information sharing, an inability to leverage co-located systems in support of a specific mission task(s), increased equipment foot-print (size, weight and power), and increased cost due to the inability to add new equipment and interfaces without significant software modifications.

The purpose of this effort is to provide an architecture and specification for a services oriented framework in a low bandwidth, low processing environment. The architecture supports the dynamic construction of protection assets while minimizing configuration requirements and allowing the enforcement of information assurance policies to ensure composition integrity and prevent intrusions from unauthorized components. The architecture takes advantage of operating within mobile networks that are characterized by varying bandwidth between nodes, availability of connections between networks, and the nature of many of the smaller footprint devices forming the nodes.

This paper will give an overview of the DFP architecture and its philosophies, concepts, and tenets. Particular attention will be given to the differences between this architecture and existing, fielded, tactical architectures as well as the differences between it and full, traditional enterprise architectures attempting to perform similar missions. Examples of the needs for the DFP capabilities will be given and explanations of how existing systems failed to meet these requirements when used in the live exercise networks. Throughout, the areas of the integration domain that are not met by existing frameworks will be given.

8389-18, Session 4

Terra harvest: ISR force multiplier

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The Defense Intelligence Agency's Terra Harvest program, begun in 2009, is developing an open, integrated battlefield unattended ground sensors (UGS) architecture. Having successfully demonstrated an UGS controller at Empire Challenge 2010, the program has since developed an array of asset plug-ins. Building on this foundation, commercial vendors are developing field-ready controller implementations for Trident Spectre 2012. Once fully operational, Terra Harvest will streamline acquisition processes, reduce employment timelines, and serve users as an ISR force multiplier.

8389-19, Session 4

Terra Harvest demonstration at Trident Spectre 2012

M. A. Kolodny, U.S. Army Research Lab. (United States)

No abstract available

8389-20, Session 4

Terra Harvest architectural overview

L. J. Tokarcik, R. P. Winkler, U.S. Army Research Lab. (United States)

Abstract- Realizing adaptive and efficient use of unattended assets within a dynamic network environment is a challenging problem. Assets are any node/platform that can be tasked and/or re-configured to produce a PAYLOAD (event/data/information/knowledge/command) which is then disseminated over a network medium. Discovery of assets, moving data from assets through gateways, archiving data locally, harvesting data for remote analysis are key capabilities that provides the foundation for a self-adaptive architecture that enables setting in motion payloads that can be utilized locally while in motion and globally when the payload come to rest within a domain specific data store. This paper describes the Terra Harvest high level architecture components for acquiring, persisting, processing, and disseminating information from unattended assets to produce a mission specific behaviors and information through the opportunistic use of domain gateways.

8389-21, Session 4

Terra Harvest software architecture

D. Humeniuk, D. M. Landoll, L-3 Communications Nova Engineering (United States)

Under the Terra Harvest Program, the DIA has the objective of developing a universal Controller for the Unattended Ground Sensor (UGS) community. The mission is to define, implement, and thoroughly document an open architecture that universally supports UGS missions, integrating disparate systems, peripherals, etc. The Controller's inherent interoperability with numerous systems enables the integration of both legacy and future UGSS components, while the design's open architecture supports rapid third-party development to ensure operational readiness. The successful accomplishment of these objectives by the program's Phase 3b contractors is demonstrated via integration of the companies' respective plug-'n-play contributions that include controllers, various peripherals, such as sensors, cameras, etc., and their associated software drivers.

In order to independently validate the Terra Harvest architecture, L-3 Nova Engineering, along with its partner, the University of Dayton Research Institute, is developing the Terra Harvest Open Source Environment (THOSE), a Java Virtual Machine (JVM) running on an embedded Linux Operating System. The Use Cases on which the software is developed support the full range of UGS operational scenarios such as remote sensor triggering, image capture, and data exfiltration. The Team is additionally developing an ARM microprocessor-based evaluation platform that is both energy-efficient and operationally flexible.

The paper describes the overall THOSE architecture, as well as the design decisions for some of the key software components. Creation and content of a developer's guide to be used by 3rd party vendors is also discussed.

8389-22, Session 4

Terra Harvest Mission programming approach

J. B. Kovach, U.S. Army Research Lab. (United States)

Terra Harvest DIA sponsored program that is developing the next generation architecture for Unattended Ground Sensors. One key element of this program is a mission programming methodology that allows standardization of the work flow required to program an UGS system. This technology is a key enabler needed to standardize the user experience. This paper describes the approach and implementation within the Terra Harvest framework.

8389-23, Session 4

How to create a Terra Harvest compliant plug in

K. Klawon, J. Gold, N. Marcucci, Univ. of Dayton Research Institute (United States)

The DIA wants to create an UGS controller that is interoperable across all controller platforms, capable of easily adding new sensors, radios, and processes, etc., as well as backward compatibility with existing UGS systems. To achieve this, the defined Terra Harvest standard is based on the latest Java JRE 1.6 and an OSGI platform. OSGI is an extensible framework that provides a modularized environment that allows functionality to be deployed in "bundles". These bundles can publish, discover, and share services available from other bundles or bundles provided by the controller core.

This session will show you how to develop and deploy a bundle for your asset, communications device, or algorithm using OSGI and the Terra Harvest Standard.

8389-24, Session 4

Interoperability testing for the Terra Harvest controller architecture

G. H. Stolovy, U.S. Army Research Lab. (United States)

The U.S. Defense Intelligence Agency (DIA) has developed the Terra Harvest standard for controller architecture to promote interoperability of Unattended Ground Sensor (UGS) components through the use of software plug-ins. This paper will describe the testing of controller implementations, sensor components, and communication devices for compliance with the standard, and describe lessons learned from tests completed to date.

8389-25, Session 4

Standard metrics for a plug-and-play tracker

J. Antonisse, Harris Corp. (United States); D. L. Young, Raytheon Intelligence & Information Systems (United States)

The Motion Imagery Standards Board (MISB) has previously established a metadata "micro-architecture" for standards-based tracking. The intent of this work is to facilitate both the collaborative development of competent tracking systems, and the potentially distributed and dispersed execution of tracker system components in real-world execution environments. The approach standardizes a set of five quasi-sequential stages in image-based tracking: image conditioning, motion detection, kinetics-based tracklet extraction, feature-based track development, and track network discovery. In the MISB standards micro-architecture for tracking, each module has well-defined outputs which provide results of independent value to the user, as well as to downstream processing. However, in order to make this plug-and-play architecture truly useful we need metrics associated with each module. This is so that, for instance, a researcher who "plugs in" a new component can ascertain whether he/she did better or worse with the component. This paper describes the choice of a set of metrics, one set for each module, which the MISB is promoting as DoD/IC/NATO standards for tracking. The metrics are based on a new, information-theoretic approach to tracking that unifies previous tracking results, and therefore form suitable standards foundations in this area.

8389-26, Session 5

A wireless near-IR retro-reflective profiling sensor

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The notion of a profiling sensor was first realized by a near-IR, retro-reflective prototype consisting of a vertical column of sparse detectors. In this prototype, the sensor's optical axis was configured perpendicular to the plane of the vertical column of detectors. Algorithms were implemented that classified objects passing through the profiling sensor's field of view into three classes of interest: humans, animals, and vehicles. Alternative arrangements of detectors have been implemented in which a subset of the detectors have been offset from the vertical column and placed at arbitrary locations along the anticipated path of the objects of interest, forming a custom detector array. Additional work was performed to determine a detector's relative location to other detectors that made up a profiling sensor and the corresponding algorithms were modified to account for the custom detector configuration. All of the prior work with the near-IR, retro-reflective profiling sensors has consisted of wired detectors and the corresponding classification algorithms were executed either off-line or on an embedded controller, which was part of the sensor. This paper advances this prior work by designing and implementing a wireless prototype version of a near-IR, retro-reflective profiling sensor in which each detector is a wireless sensor node. In this novel architecture, a base station is responsible for collecting all data from the detector sensor nodes and coordinating all pre-processing of data collected from the sensor nodes, including data re-alignment before subsequent classification algorithms are executed. Such a wireless detector configuration advances deployment options for near-IR, retro-reflective profiling sensors.

8389-27, Session 5

Unattended devices for determining intent and modifying behavior

R. B. Sartain, Primal Innovation (United States)

Today's Unattended Ground Sensors have the capability to automatically determine if the object passing the sensor is human, animal or vehicle. This paper presents a concept for what happens once humans have been detected. If the unattended device has the capability to provide a stimulus the humans may react to the stimulus. If the device or networked devices have the capability to detect and classify the reactions then it maybe possible to determine intent (good or bad) and to modify the behavior of the humans. This paper explores concepts for how this maybe accomplished using low cost, power, and weight devices.

Stimulus include both acoustic and light with multiple reactions considered for each stimulus. An obvious example would be that once humans have been detected a stimulus is provided that makes it obvious that they have been detected. If the humans reverse their direction of travel (they go back the way they came)then one might draw conclusions on potential intent. If the humans quickly stop for a short period of time then continue in the same direction of travel a different intent may be considered.

Consideration is also given to layers of stimulus and reactions to collect information required for Intent Data to Decision tools or aids.

8389-28, Session 5

Soldier detection using unattended acoustic and seismic sensors

P. Naz, S. Hengy, P. Hamery, Institut Franco-Allemand de Recherches de Saint-Louis (France)

During recent military conflicts, as well as for security interventions, the urban zone takes a preponderant place. Studies have been initiated in national and in international programs. For example joint field experiments have been organized by NATO group SET-142 to evaluate the capability for the detection and localization of snipers, mortars or artillery guns using acoustics.

Another important operational need corresponds to the protection of military sites or buildings. In this context unattended acoustic and seismic sensors are envisaged to contribute to the survey of specific points by the detection of individual enemy soldiers approaching.

This paper describes some measurements done in an anechoic chamber and in free field to characterize typical sounds generated by the soldier activities (walking, crawling, weapon handling, radio communication, clothing noises,...). Footstep, speech and some specific impulsive sounds are detectable at various distances from the source. Such detection algorithms may be easily merged with the existing weapon firing detection algorithms to provide a more generic "battlefield acoustic" early warning system.

Results obtained in various conditions (grassy terrain, gravel path, road, forest) will be presented. A method to extrapolate the distances of detection has been developed, based on an acoustic propagation model and applied to the laboratory measurements.

8389-29, Session 5

Intent-based resource deployment in wireless sensor networks

G. R. de Mel, Univ. of Aberdeen (United Kingdom); T. Pham, U.S. Army Research Lab. (United States); F. Bergamaschi, IBM United Kingdom Ltd. (United Kingdom); W. Vasconcelos, T. J. Norman, Univ. of Aberdeen (United Kingdom)

Information derived from sensor networks plays a crucial role in the success of many critical tasks such as surveillance, and border monitoring. In order to derive the correct information at the right time, sensor data must be captured at desired locations with respect to the operational tasks in concern. Therefore, it is important that at the planning stage of a mission, sensing resources are best placed in the field to capture the required data. For example, consider a mission goal 'identify snipers' in an operational area before troupes are deployed - two acoustic arrays and a day-night video camera are needed to successfully achieve this goal. This is because, if the resources are placed in correct locations, two acoustic arrays could provide direction of the shooter and a possible location by triangulating acoustic data whereas the day-night camera could produces an affirmative image of the perpetrators.

In order to deploy the sensing resources intelligently to support the user decisions, in this paper we propose a Semantic Web based knowledge layer to identify the required resources in a sensor network and deploy the needed resources through a sensor infrastructure. The knowledge layer captures crucial information such as resources configurations, their intended use (e.g., two acoustic arrays deployed in a particular formation with day-night camera are needed to identify perpetrators in a possible sniper attack). The underlying sensor infrastructure will assists the process by exposing the information about deployed resources, resources in theatre, and location information about tasks, resources and so on.

8389-30, Session 5

A multimodal, temporal panorama approach for moving vehicle detection, reconstruction, and classification

T. Wang, Z. Zhu, The City College of New York (United States); C. N. Taylor, Air Force Research Lab. (United States)

In this work, we present a multimodal temporal panorama (MTP) representation that synchronizes visual, motion, and acoustic signatures of moving vehicles in the time axis. The MTP representation includes two layers: a synopsis layer and a snapshot layer. The temporal synopsis consists of 1) a panoramic view image (PVI) to represent vehicles' presence, which is constructed from 1D vertical detecting lines of a selected column location of all video frames; 2) an epipolar plane image (EPI) to characterize their motion (speeds and directions), generated from 1D horizontal scanning lines along the vehicles' moving paths; and 3) an audio wave scroll for visualizing moving vehicles' acoustic signatures. The MTP synopsis not only synchronizes all the three modalities (visual, motion and acoustic) of the vehicles, but also provides information that can perform automatic detection tasks including moving vehicle visual detection, motion estimation, and acoustic signature retrieval. Then in the snapshot layer, the occlusion-free, motion-blur-free, and view-invariant reconstruction of each vehicle (with both shape and motion information) and its acoustic signatures (e.g. spectrogram) are embedded. The MTP provides a very effective approach to (semi-)automatically labeling the multimodal data of uncontrolled traffic scenes in real time for further vehicle classification, check-point inspection and traffic analysis. The concept of MTP may not be only limited to visual, motion and audio modalities; it could also be applicable to other sensing modalities that can obtain data in the temporal domain.

8389-31, Session 5

Consensus of stochastic maps with nearest neighbor interactions

B. M. Jones, M. Campbell, L. Tong, Cornell Univ. (United States)

The problem of constructing a spatial consensus map based on the decentralized and aperiodic exchange of information between n mobile agents is considered. Associated with each agent at time k is a variable dimension stochastic map, built within the coordinate system of the respective agent based on noisy sensor measurements and controls. Although the agents are capable of exchanging map information with a time-varying set of cooperating neighbor agents, the common information between the maps is initially unknown. The objective of two agents in communication range is to determine an exchange policy such that the expected value of information exchange (EVIE) is maximized. In this paper, we propose an exchange policy based on the maximum likelihood principle in addition to an EVIE metric. Simulation results are provided which demonstrate scenarios where the proposed exchange policy by n mobile agents results in a consensus of stochastic maps.

8389-32, Session 5

Trust and obfuscation

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In modern coalition operations, decision makers must be capable of obtaining and fusing data from diverse sources. The reliability of these sources may be variable, and, in order to protect their interests, the data they provide may be obfuscated. The trustworthiness of fused data is dependent not only on the reliability of the sources, but also on the type and extent of the obfuscation used. New problems arise for both data providers and consumers in these contexts; the consumers must determine how to evaluate the trustworthiness of providers in the presence of differing levels of obfuscation, while the providers must be able to determine the appropriate level of obfuscation to ensure that trust in them is maintained. Obfuscation is then necessary, and even desirable, to encourage information sharing in diverse coalitions by reducing the percieved risk for producers. There exists then a need for techniques which facilitate appropriate obfuscation, and reasoning with obfuscated data. Addressing this need requires an understanding of the complex relation-ship between obfuscation and trust. In this paper, we discuss trust and obfuscation in these contexts and the complex relationships between them.

8389-33, Session 5

Sharing protected sensory data in coalition environments

J. R. James, F. Mabry, K. Huggins, U.S. Military Academy (United States)

We describe a new capability for "owners" of protected sensory data to quickly and securely share real-time data among networked decision-support and real-time control devices with whom the "owners" of the data have explicitly decided to "share the data. Current coalition warfare environments share data among all users who are "on the net" after providing appropriate credentials. Such coarse-grained information sharing approaches have led to Wiki-leaks. Our approach enables fine-grained sharing of data with selected users and groups. The service is based upon implementation of a recent formal definition and mathematical result (James et al. 2009) derived from the decades-old Bell-LaPadula information security result (Bell and LaPadula, 1973). The service provides decision makers a means of securely and automatically sharing critical information across security barriers based upon declaration of sharing policies. The declaration and implementation of information sharing policies based upon a need-to-share has been shown to be compatible with information protection policies based upon a need-to- know. Indeed, the implementation of the need-to- share service is based upon extending the mathematical foundations of need-to-know information security systems (the Bell-LaPadula result of 1973).

8389-34, Session 5

Levy walks for autonomous search

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Unmanned vehicles (UAVs) are playing an increasingly successful-role in the battlefield arena including but not limited to surveillance, reconnaissance and aerial interdiction. The challenge with the increased usage of UAVs is that each one requires a team of skilled individuals to conduct a single mission. Thus, there is a compelling need for unmanned systems to become capable in their own right.

A canonical problem for autonomy is search and discovery. Often, searching needs to be unpredictable in order to be effective. In this paper, we investigate and compare the effectiveness of the traditional and predictable lawnmower search strategy to that of a random search. Specifically the family of searches with paths determined by heavy tailed distributions called Lévy stable searches is investigated. These searches are characterized by long flight paths, followed by a new random direction, with the flight path lengths determined by the distribution parameter α. Two basic search scenarios are considered in this study: stationary targets, and moving targets, both on planar surfaces. Monte-Carlo simulations demonstrate the advantages of Lévy over the lawnmower strategy especially for moving targets.

Ultimately to corroborate the suitability of the Lévy strategy for UAVs, we implement and demonstrate the feasibility of the algorithm in the Multiple Unified Simulation Environment (MUSE), which includes vehicle's constraints and dynamics. The MUSE / Air Force Synthetic Environment for Reconnaissance and Surveillance (AFSERS) simulation system is the primary virtual ISR and UAV simulation used within the DOD for command and staff level training for the Joint Services.

8389-35, Session 5

Source localization corrections for airborne acoustic platforms based on a climatological assessment of temperature and wind velocity profiles

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Acoustic sensors are being employed on airborne platforms, such as Persistent Threat Detection System (PTDS) and Persistent Ground Surveillance System (PGSS), for source localization. Under certain atmospheric conditions, airborne sensors offer a distinct advantage over ground sensors. The performance of both is affected by environmental factors, such as atmospheric turbulence, wind and temperature profiles, irregular terrain, impedance ground, and reflecting obstacles. For airborne sensors, the effects of refraction must be accounted for in order to determine the source coordinates. Such a method for ground-to-air applications has been developed and is herein further refined. Atmospheric turbulence may significantly affect both azimuth and elevation estimation. Ideally, exact knowledge of the atmospheric profiles and turbulence conditions will allow for the most accurate mitigation of these effects. However, acoustical systems deployed in theater typically are not supported by real-time, atmospheric observations of the temperature and wind fields. Atmospheric conditions evolve through seasons, time of day, and are strongly location dependent. Therefore, the development of an atmospheric profiles database based on a long time series climatological assessment will provide knowledge for use in these physics-based bearing estimation algorithms, where otherwise no correction would have been performed. Long term atmospheric datasets are also available from weather modeling systems. Here we use such data in order to perform a climatological assessment of the refraction corrections and localization errors over selected sites.

8389-36, Session 6

An architecture for distributed video applications based on declarative networking

X. Wang, C. Gonzales, J. Lobo, S. Calo, D. Verma, IBM Thomas J. Watson Research Ctr. (United States)

Video surveillance applications are examples of complex distributed coalition tasks. Real-time capture and analysis of image sensor data is one of the most important tasks in a number of military critical decision making scenarios. In complex battlefield situations, there is a need to coordinate the operation of distributed image sensors and the analysis of their data transmitted over a heterogeneous wireless network where bandwidth, power, and computational capabilities are constrained. There is also a need to automate decision making based on the results of the analysis of video data. Declarative Networking is a promising technology for controlling complex video surveillance applications in this sort of environment. This paper presents a flexible and extensible architecture for deploying distributed video surveillance applications using the declarative networking paradigm, which allows us to dynamically connect and manage distributed image sensors and deploy various modules for the analysis of video data to satisfy a variety of video surveillance requirements. With declarative computing, it becomes possible for us not only to express the program control structure in a declarative fashion, but also to simplify the management of distributed video surveillance applications.

8389-37, Session 6

From information needs to information gathering: a system optimization perspective to ISR synchronization

M. Sudit, H. Ortiz-Pena, M. Moskal, CUBRC (United States); J. Fink, D. Tuttle, T. Hanratty, E. Heilman, M. Dawson, U.S. Army Intelligence Ctr. (United States)

There has been significant progress recognizing the value of Intelligence, Surveillance, and Reconnaissance (ISR) activities supporting Situational Awareness (SA) and Command and Control (C2) functions during the past several decades. We consider ISR operations to be proactive (discovering activities or areas of interest), active (activities performed for a particular task that flows down from a hierarchical process) or reactive (critical information gathering due to unexpected events). ISR synchronization includes the analysis and prioritization of information requirements, identification of intelligence gaps and the recommendation of available resources to gather information of interest, for all types of ISR operations. It has become critically important to perform synchronized ISR activities to maximize the efficient utilization of limited resources (both in quantity and capabilities) and, simultaneously, to increase the accuracy and timeliness of the information gain. A study evaluating the existing technologies and processes supporting ISR activities is performed suggesting a rigorous system optimization approach to the ISR synchronization process. Unfortunately, this approach is not used today. The study identifies existing gaps between the current ISR synchronization process and the proposed system optimization approach in the areas of communication and collaboration tools, advanced decision aids (analytics), and sensor technologies. Solutions are recommended that will help closing this gap. The benefits of adopting such a system optimization approach for ISR synchronization are also demonstrated.

8389-38, Session 7

Low-latency situational awareness for UxV platforms

D. Berends, SRI International Sarnoff (United States)

Providing high quality video from unmanned vehicles through bandwidth-limited communications channels remains a formidable challenge for modern vision system designers. Typical UAV/UGV CONOPS require that these systems achieve low end-to-end latencies while displaying fused multispectral imagery on relatively small tablet and laptop computer displays, further complicating the system designer's challenge. Add to this the demanding SWaP requirements of these platforms plus the strong desire for digital video and communications in support of encryption, recording and networking, and the challenge can rapidly become overwhelming.

SRI Sarnoff has developed a number of enabling technologies in support of these system requirements, including the effective use of SWaP-optimized System-on-Chip technologies to both provide low latency image processing-including Pyramid-based multispectral fusion and Contrast Enhancement-as well as ultra low latency H.264 image compression. Further, SRI's application of salience-based image prefiltering prior to compression greatly reduces the video data bandwidth by selectively blurring the non-important regions of the scene-such as large homogenous farm fields of wherein the proper

representation of each and every wheat stalk provides no value to the viewer but typically requires a great deal of communications bandwidth-while leaving the important ("salient") regions of interest undisturbed.

SRI has also worked with open source LINUX and Windows video viewers to support low latency image decoding on portable platforms, including smartphones, tablets and ruggedized laptops. The combination of these enabling technologies results in high performance, high quality vision systems for UAV/UGV applications in support of even the most demanding CONOPS.

8389-39, Session 7

Acoustic data analysis and scenario overwatch from an aerostat at the NATO SET-153 field experiment

C. G. Reiff, U.S. Army Research Lab. (United States)

The purpose of the NATO SET-153 field experiment was to provide an opportunity to demonstrate multiple sensor technologies in an urban environment and determine integration capabilities for future development. The Army Research Laboratory (ARL) experimental aerostat was used primarily as a persistent overwatch capability as a substitute for a UAV. Continuous video was recorded on the aerostat and segments of video were captured of the scenarios on the ground that the camera was following manually. Some of the segments showing scenario activities will be presented. The captured pictures and video frames have telemetry in the headers that provides the UTM time and the Inertial Navigation System (INS) GPS location and the inertial roll, pitch, and yaw as well as the camera gimbal pan and tilt angles. The timing is useful to synchronize the images with the scenario events providing activity ground truth. The INS, GPS, and camera gimbal angle values can be used with the acoustic solution for the location of a sound source to determine the relative accuracy of the solution if the camera is pointed at the sound source. This method will be confirmed by the use of a propane cannon whose GPS location is logged. During the field experiment, other interesting acoustic events such as vehicle convoys, platoon level firefights with vehicles using blanks, and a UAV helicopter were recorded and will be presented in a quick analysis.

8389-40, Session 8

A decentralized approach for multi-UAV, multitarget tracking and surveillance

E. Adamey, U. Ozguner, The Ohio State Univ. (United States)

In this paper, we consider the problem of cooperative multitarget tracking and surveillance with multiple UAVs in a decentralized network architecture. In sensor fusion, we developed a decentralized particle filtering approach to maintain target location estimates. Sample sets are converted to Gaussian Mixtures using expectation maximization, and communicated between agents using a request/response strategy. Upon receiving Gaussian Mixtures from other agents, each UAV fuses them to its own estimate using generalized covariance intersection. In decision making, we decoupled the problem into two abstraction levels. In higher level, leaders are selected for each subnetwork. Each leader, then, assigns operating regions to other agents within its subnetwork. In lower level, individual agents plan their own motions to actively track targets within their assigned regions. Our approach is evaluated in a number of simulation runs. The results demonstrate the effectiveness of our decentralized approach.

8389-41, Session 8

Wide-area littoral discreet observation: success at the tactical edge

A. P. Ladas, U.S. Army Research Lab. (United States); S. D. Toth, Air Force Research Lab. (United States)

The aero-optical effects of a Mach 0.5 turbulent boundary layer are analyzed using the fluctuating density field obtained from large-eddy simulations. Important issues such as Reynolds number dependence of OPD, contributions from different flow regions and flow scales to the wavefront aberrations, and the dependence on propagation direction, are examined. The numerical database is further used to simulate Malley probe and 2-D wavefront sensor measurements and investigate their differences in terms of OPDrms, correlation lengths, and the effects of aperture size and unsteady tilt removal. The similarities and differences in optical distortions caused by attached boundary layers and separated shear layers are also discussed.

8389-42, Session 8

Autonomous UAV persistent surveillance using bio-inspired strategies

J. A. Burman, Teledyne Scientific Co. (United States); J. P. Hespanha, U. Madhow, Univ. of California, Santa Barbara (United States); T. Pham, U.S. Army Research Lab. (United States)

A team consisting of Teledyne Scientific Company, the University of California at Santa Barbara, the Army Research Laboratory, the Engineer Research and Development Center, and IBM UK is developing technologies in support of automated data exfiltration from heterogeneous battlefield sensor networks to enhance situational awareness for dismounts and command echelons. Unmanned aerial vehicles (UAV) provide an effective means to autonomously collect data from a sparse network of unattended ground sensors (UGSs) that cannot communicate with each other. UAVs are used to reduce the system reaction time by generating autonomous collection routes that are data-driven. Bio-inspired techniques for autonomous search provide a novel strategy to detect, capture and fuse data from heterogeneous sensor networks. The bio-inspired algorithm is based on chemotaxis or the motion of bacteria seeking nutrients in their environment. Field tests of a bio-inspired system that routed UAVs were conducted in June 2011 at Camp Roberts, CA. The field test results showed that such a system can autonomously detect and locate the source of terrestrial events with very high accuracy and visually verify the event. In June 2011, field tests of the system were completed and include the use of multiple autonomously controlled UAVs, detection and disambiguation of multiple acoustic events occurring in short time frames, optimal sensor placement based on local phenomenology and the use of the International Technology Alliance Sensor Network Fabric. The system demonstrated TRL 6 performance in the field.

8389-43, Session 8

Cooperative layered sensing: a factor analysis on finding elusive mobile targets

C. K. Curtis, Air Force Research Lab. (United States); J. M. Colombi, Air Force Institute of Technology (United States)

Irregular asymmetric conflicts with non-traditional targets and shorter timelines are spawning new mission requirements for situation awareness. As a result, the increasing demands for timely decision-quality information across the battle space have presented tough challenges for stretched operational resources. The Layered Sensing construct developed by the Air Force Research Laboratory provides a unified vision for research to address the situational awareness challenges posed by the complex and dynamic environments seen in

recent conflicts. Determining how to maximize available resources across the battle space with the best efficiency and effectiveness is a critical research thread in the Layered Sensing construct. Leveraging different capabilities across networked cooperative sensors to provide timely situational awareness is critical in accomplishing mission objectives with limited resources. This paper evaluates cooperative sensing using a constructive simulation environment by examining mission performance in various scenarios where Remotely Piloted Aircraft are seeking elusive mobile targets. Measured performance parameters include enemy targets killed and suppression of enemy missile attacks. Cooperative and non-cooperative conditions were simulated using variable factors: sensor capabilities, target densities and false target densities. Results demonstrate statistically significant mission performance improvements of over 200% for less capable, but cooperatively networked, sensors increasing their effectiveness to that of more capable sensors working alone. Key factors regarding when and how to leverage cooperation for improved mission performance are also identified and examined through sensitivity analysis.

8389-44, Session 8

Performance-based dynamic team formation in multi-agent auctions

C. E. Pippin, Georgia Tech Research Institute (United States); H. I. Christensen, Georgia Institute of Technology (United States)

In distributed, heterogeneous, multi-agent teams, agents may have different capabilities and types of sensors. However, in dynamic environments teams of agents will need to cooperate in real-time to perform tasks with minimal costs. Some example scenarios include dynamic allocation of UAV and UGV robot teams to possible hurricane survivor locations to search for survivors or to deliver goods.

Auction based methods are often used to perform distributed task allocation on multi-agent teams. Many existing approaches to auctions assume fully cooperative team members, and team members may have cooperation explicitly built in. However, on in-situ and dynamically formed teams, reciprocal collaboration may not always be a valid assumption.

This paper presents an approach for dynamically selecting auction partners based on observed team member performance and shared reputation information. Multiple dimensions of trust and task performance are presented for evaluating team member performance, along with monitoring approaches. In addition, we present the use of a shared reputation mechanism in a practical setting. Each team member begins with a priori information about other individuals and this model is updated through repeated interactions. Agents can use the model to detect team members that are not contributing, and those team members can be removed from future collaboration, thereby losing the benefits of cooperation. Finally, experiments are performed in simulation on multiple UAV platforms to highlight situations in which it is beneficial to enforce cooperation in auctions using this approach.

8389-45, Session 8

Performance modeling of a feature-aided tracker

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The current surveillance domain includes sensor data from multiple modalities. Data exploitation algorithms can be utilized to distill this sensor data into actionable information in a timely manner. The outputs of these algorithms typically produce an estimate of state. However, there is a need to also produce a confidence in the state estimation to facilitate sensor fusion. The confidence reported by the algorithm combines knowledge of the operating conditions in conjunction with the observed signature. In this paper we present the results of one such algorithm for feature-aided tracking of vehicles in wide area motion imagery. Due to the large dimensionality of the operating condition space, a synthetic environment was developed that produced data similar to typical wide area motion imagery. This allowed explicit control of operating conditions and also provided ground truth for vehicle state. This synthetic environment leveraged physics-based modeling simulations to re-create traffic flow, vehicle reflectance, obscuration and shadowing. The results demonstrated that the performance model produces a meaningful estimate of the tracker performance over a subset of operating conditions.

8389-46, Session 8

Threshold considerations in distributed detection in a network of sensors

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We consider the problem of distributed sensing and detection using a network of sensor nodes and the challenges that arise in fusing disparate data. Multiple sensors make local inferences on the state of nature (e.g., the presence of a signal), and those observations are then transmitted to a global fusion center. The fusion center is tasked to make improved decisions. We develop methods to optimize those decisions.

Interoperability between disparate sensor nodes can be addressed by combining similar types of parameters (e.g., direction of arrival and location estimates to better infer location), albeit with varying qualities. As an initial problem, we consider the case where each sensor makes a binary decision on the presence of a signal source and the fusion node combines these to make a more accurate decision. Even in this simple case, the cost of directly determining the global performance grows exponentially with the number of sensors and can be impractical for just tens of sensors. Instead, we use Chernoff bounds as surrogates for evaluating global performance. These bounds provide tractable methods for analysis and constrained optimization.

We consider a lossy medium in which signals undergo a range-dependent propagation loss. We determine local thresholds that optimize a performance metric, including both constrained global detection performance and asymptotic error performance. We study the effect of propagation loss and sensor node density on these performance metrics. The performance metrics also provide indicators of the amount of value that each sensor contributes to the fusion task.

8389-47, Session 8

Creation of a wide-area-motion imagery capture system for small UAVs

C. N. Taylor, D. Uppenkamp, J. Stadler, Air Force Research Lab. (United States)

With the continued miniaturization of electronics and sensors, it has become possible to collect a large amount of data from smaller and smaller platforms. However, miniaturization itself is not sufficient for enabling novel applications of utility to the end-user. In this paper, we describe a system developed to enable collection and dissemination of wide area motion imagery (16 MPixel, color, at 4Hz) from a small unmanned aerial vehicles (UAV). The system was created using commercial components for the imager and all computational units, with custom software for capturing, archiving, communicating, and preparing for display the imagery. Specifically, we focus on the novel software and usage scenarios developed for this system.

The software created for this system consists of four main components: (1) the on-board system, (2) the ground-based data reception station, (3) the visualization preparation system, and (4) the visualization station. We describe the novel components implemented in each sub-system and the interaction between the sub-systems. We also present some sample images captured by this system in a field exercise in New York. The results from this demonstrate the feasibility of creating a system for wide-area motion imagery capture using a small (<15ft wingspan) UAV.

8389-48, Session 8

Indoor situational awareness exploiting robotic platforms

M. D'Urso, A. Buonanno, G. Prisco, SELEX Sistemi Integrati S.p.A. (Italy); F. Meliadò, Consorzio SESM (Italy); M. Felaco, SELEX Sistemi Integrati S.p.A. (Italy)

The development of intelligent surveillance systems is an active research area, of increasing interest. In this context, mobile and multi-functional robots have been recently adopted as successful means to reduce fixed installations and the number of devices needed to cover a given area. On the other hand, modern techniques for data fusion and decision making can significantly increase the information content extracted from sensors both mounted on the robots and on the infrastructure. The use of many heterogeneous sensors, the number and complexity of operational tasks required for monitoring and surveillance with autonomous components like robots makes the overall system design very challenging. In this paper we present some ideas and investigations ongoing in SELEX Sistemi Integrati to assess the capability of such a kind of robots-sensors systems to improve the monitoring of large and densely populated indoor areas. In particular a discussion on some of the problems arising in robot guidance and navigation, oriented to the reduction of missed and false alarms is firstly carried out. Interesting results on the indoor map building problem will be also reported and discussed. Numerical and experimental results are reported to support the proposed investigations. Conclusions follow

8389-50, Session 9

Why social network analysis is important to Air Force applications

P. R. Havig II, J. P. McIntire, E. E. Geiselman, Air Force Research Lab. (United States)

Social network analysis is a powerful tool used to help analysts discover relationships amongst groups of people as well as individuals. It is the mathematics behind such social networks as Facebook and Myspace. This in itself causes a huge amount of data to be generated, especially once one adds in other electronic media such as e-mails and twitter. In this paper we outline the basics of social network analysis and how it may be used in current and future Air Force applications.

8389-51, Session 9

Persistent ISR: the social network analysis connection

E. K. Bowman, U.S. Army Research Lab. (United States)

Persistent sensors provide decision makers with unprecedented access to multisource data collected from around the globe [1]. Advances in online social networking offer an opportunity to use social network analysis (SNA) as an evolutionary sensor technology. While persistent Intelligence, Surveillance, and Reconnaissance (ISR) assets will remain vital to military operations, SNA can aid qualitative tactical awareness, as an augment to traditional sensors. This is demonstrated by the wave of reform that swept the North African nations in early 2011. Demonstrators made widespread use of social networking applications to coordinate, document, and publish material to aid their cause [2]. A harbinger of this revolution was the 2009 Iranian election protests where dissatisfied Iranians, faced with questionable election results, biased state media and the prohibition against opposition newspapers, organized protests and published information through online social sites [3]. Unlike members of covert social networks who hide their activity and associations [4], these demonstrators openly posted multimedia data to stimulate global support. This paper argues that SNA is increasing in relevance to persistent ISR at a time when physical sensors are becoming less relevant, due in large part to the inability of processing algorithms to keep up with the overwhelming influx of persistent data. [5]. We provide a review of SNA approaches, measures, and recent innovations in capturing temporal and conceptual aspects of network adaptation. We propose opportunities and challenges for merging SNA with physical sensor output, and conclude by addressing future challenges in the persistent ISR domain with respect to SNA.

8389-52, Session 9

Visualizing weighted networks: a performance comparison of adjacency matrices versus node-link diagrams

J. P. McIntire, Air Force Research Lab. (United States); O. I. Osesina, C. Bartley, M. E. Tudoreanu, Univ. of Arkansas at Little Rock (United States); P. R. Havig II, E. E. Geiselman, Air Force Research Lab. (United States)

Ensuring the proper and effective ways to visualize network data is important for many areas of academia, applied sciences, the military, and the public. Fields such as social network analysis, genetics, biochemistry, intelligence, cybersecurity, neural network modeling, transit systems, communications, etc. often deal with large, complex network datasets that can be difficult to interact with, study, and use. There have been surprisingly few human factors performance studies on the relative effectiveness of different graph drawings or network diagram techniques to convey information to a viewer. This is particularly true for weighted networks which include the strength of connections between nodes, not just information about which nodes are linked to other nodes. We describe a human factors study in which participants performed three separate network analysis tasks (finding a link between target nodes, finding a single node between target nodes, and estimating the most densely interconnected nodes) on two different network visualizations (adjacency matrix with a heat-map versus a node-link diagram) in a repeated measures design. The results should help shed light on effective methods of visualizing network data on some representative analysis tasks, with the ultimate goal of improving usability and performance for viewers of network data displays.

8389-53, Session 9

Methods for extracting social network data from chatroom logs

O. I. Osesina, Univ. of Arkansas at Little Rock (United States); J. P. McIntire, P. R. Havig, E. E. Geiselman, Air Force Research Lab. (United States); C. Bartley, M. E. Tudoreanu, Univ. of Arkansas at Little Rock (United States)

Identifying social network (SN) links within computer-mediated communication platforms without explicit relations among users poses challenges to researchers. Our research aims to extract SN links in internet chat with multiple users engaging in synchronous overlapping conversations all displayed in a single stream. We approached this problem using three methods which build on previous research. Response-time analysis builds on temporal proximity of chat messages; word context usage builds on keywords analysis and direct addressing which infers links by identifying the intended message recipient from the screen name (nickname) referenced in the message (Mutton 2004). Our analysis of word usage within the chat stream also provides contexts for the extracted SN links. We used publicly available data from Internet Relay Chat (IRC), a real-time computer-mediated communication (CMC) tool used by millions of people around the world to test the capability of our methods. The extraction performances of individual method and their hybrid were assessed relative to and a ground truth determined a priori via manual scoring.

8389-54, Session 9

Identifying rumors and their sources in social networks

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Information that propagates through social networks can carry a lot of false claims. For example, rumors on certain topics can propagate rapidly leading to a large number of nodes reporting the same (incorrect) observations. In this paper, we describe an approach for assessing the likelihood that a piece of information is in fact a rumor, and for inferring the most likely source of the rumor in the social network, in the absence of data provenance information. We model the social network as a directed graph, where vertices represent individuals and directed edges represent information flow (e.g., who follows whom on Twitter). A number of monitor nodes are injected into the network whose job is to report data they receive. Our algorithm identifies rumors and their sources by observing which of the monitors received the given piece of information and which did not. While the problem has exponential complexity, we present a polynomial approximation and show that, with a sufficient number of monitor nodes, it is possible to recognize most rumors correctly and pinpoint their originators with high accuracy.

8389-55, Session 9

Increasing situational awareness using smartphones

S. K. Boddhu, MetaCarta, a Division of Qbase (United States); R. L. Williams, Tec^Edge Innovation and Collaboration Ctr. (United States) and Air Force Research Lab. (United States)

In recent years, United States Armed services and other Law-enforcement agencies have shown increasing interest in evaluating the possibility of recommending smartphones and hand-held devices as part of the standard gear for its personnel, performing duties on battlefield or in crime-prone areas. The primary motivation driving these analysis efforts to leverage smartphone based technologies, is the prospect of increased “Situational Awareness” that can be achieved thru a digitally connected network of armed personnel, equipped with customized smart applications that use device’s sensors (GPS, Camera, Compass, etc...) to sense the hostile environments and also enable them to perform collaborative tasks to effectively complete a given mission. In this vein, during the Summer At The Edge (SATE) -2011, a group of student interns have employed smartphones and built three smart applications, to tackle three real-world scenarios, namely; (1) PinPoint- A collaborative smart application that uses a network of three smartphones and their audio sensors to perform sound localization., (2) IStream- A smart application that uses the camera sensor on the smartphone and streams the camera feed to a localized video server for archival and real-time streaming to Layered Sensing Visualization platforms (like OpenLST command center)., and (3) Cooperative GPS- A collaborative smart application that uses the GPS sensor on the smartphone along with external sensor hardware to accurately determine a more precise GPS location. The successful development and field testing of these three prototype apps have provided sufficient evidence and implications to collectively support the prospective of employing smartphones to increase “Situational Awareness” by conceptually forming reliable digital “Eyes and Ears” of the armed personnel in hostile environments.

8389-56, Session 9

Cyber security and data collection approaches for smartphone sensor systems

J. White, Virginia Polytechnic Institute and State Univ. (United States)

Traditional cyber-physical system (CPS) applications for monitoring disasters have relied on specialized, tightly-coupled, and expensive hardware and software platforms to capture, aggregate, and disseminate information on affected areas. The recent proliferation of smartphones based on the Android and iOS software platforms have sophisticated sensor packages, high-level programming APIs, and multiple network connectivity options that have attracted significant interest for building mobile CPS applications. Likewise, cloud computing infrastructures are increasingly being used to collect and aggregate data from mobile applications in a manner that can precisely tailor computing resources to required workloads.

This paper presents work on CLEAR, a smartphone and cloud-based system for allowing “citizen scientists”, which are citizens trapped in a disaster area, to provide sensing and situational awareness data to first-responders. The paper describes the architecture of CLEAR and discusses key challenges and current solution approaches for securing sensitive information collected from these citizen scientist data collection systems. Research on secure policy-based mechanisms for protecting sensitive situational awareness data on first-responder mobile devices is also discussed.

8389-57, Session 9

Social network innovations in persistent surveillance: an avatar’s perspective

R. L. Williams, B. McKinney, Air Force Research Lab. (United States)

A virtual command center was developed under the Air Force Research Laboratory’s Summer at the Edge (SATE) research internship program. The research involved using virtual reality technology to demonstrate and test the ability to integrate data streams from multiple image and non-image based data sources from an avatar’s perspective. A prototype was develop as part of the Air Force Discovery Lab project to evaluate virtual reality command center designs. Several functions were investigated: (1) the ability to alert authorities to natural or man-made disaster, (2) ability to provide virtual emergency response training for any conceivable situation (3) situation table to load and test variety of emergency response options (4) ability to alert authorities in order to deploy response to any situation and (5) framework for researching and developing social network connectivity for persistent ISR and adaptive mission planning.

Conference 8390: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVIII

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8390-01, Session 1

Progress in the theory of continuum fusion

A. P. Schaum, U.S. Naval Research Lab. (United States)

The continuum fusion (CF) theory of signal detection defines new families of solutions for each member of the class of composite hypothesis (CH) testing problems. A subset of those problems admit uniformly most powerful solutions (UMPs). It is shown that one general CF method can always be used to find an UMP solution, if it exists. No other methodology is known to provide such a guarantee. Certain other problems, motivated by hyperspectral sensing and lacking UMP solutions, are also examined. For these the standard algorithms derived from the generalized likelihood ratio test are demonstrably undesirable, while several continuum fusion methods are shown to yield the same robust solution. Related new metrics of performance are proposed that rank algorithm performance for the general class of CH problems. Finally, outstanding theoretical issues in continuum fusion are described.

8390-02, Session 1

Clairvoyance and confusion: some remarks on the composite hypothesis testing problem

J. Theiler, Los Alamos National Lab. (United States)

Statistical hypothesis testing provides a useful framework for detecting targets that are small or weak or rare (in short, that are difficult to detect) in cluttered backgrounds. The null hypothesis is that there is no target, while the alternative hypothesis states that a target is present. When there are unknown parameters (such as the size or strength of the target), the alternative hypothesis is composite.

The holy grail of composite hypothesis testing is the uniformly most powerful (UMP) test, but very few problems admit a UMP detector. There can be many detectors and no clear way to choose one over another. Among these are the “clairvoyant” detectors; each is optimal for a specific parameter value, but since that parameter value is unknown, this optimality cannot be directly exploited. The generalized likelihood ratio (GLR) is the classic solution; but it is not the only solution and (except for a very few cases) it is not the optimal solution.

Among the alternatives to GLR are the recently suggested “continuum fusion” detectors. Continuum fusion comes in many flavors, and in fact GLR is one of them. A Bayesian approach provides yet another family of detectors. What all of these have in common is that they are obtained by fusing the clairvoyant detectors.

Using these various approaches, detectors are derived for the additive target model when the background is an elliptically-contoured distribution, and their performance is compared. No detector is uniformly best, but we observe the conditions under which some detectors outperform others.

8390-03, Session 1

A hyperspectral anomaly detector based on maximized subspace model in local mode

E. Lo, Susquehanna Univ. (United States)

An algorithm for detecting man-made anomalies in a natural background using hyperspectral imaging is presented. A data cube is whitened using a subspace model in global mode. The subspace model used is based on maximizing the squared correlation between each component of the pixel and the high-variance principal components. The whitened data cube is sampled by partitioning the spatial dimension and also by using a sliding window. The local sample statistics are obtained by using robust statistics. Experimental results using a real hyperspectral imagery are presented and compared with bench-mark hyperspectral anomaly detectors.

8390-04, Session 1

Kernel sparse representation for hyperspectral target detection

Y. Chen, The Johns Hopkins Univ. (United States); N. M. Nasrabadi, U.S. Army Research Lab. (United States); T. D. Tran, The Johns Hopkins Univ. (United States)

A nonlinear kernel-based classifier for hyperspectral target detection is proposed in this paper. The proposed approach relies on sparsely representing a test sample in terms of all the training samples in a high-dimensional feature space induced by a kernel function. Specifically, the feature representation of a test pixel is assumed to be compactly expressed as a sparse linear combination of few atoms from a training dictionary consisting of both background and target training samples in the same feature space. The sparse representation vector is obtained by decomposing the test pixel over the training dictionary via a kernelized greedy algorithm, which uses the kernel trick to avoid explicit evaluations of the data in the feature space. The class label is then determined by comparing the reconstruction accuracy with respect to the background and target sub-dictionaries using the recovered sparse vector. Designing the classifier in a high-dimensional feature subspace will implicitly exploit the higher-order structure (correlations) within the data which cannot be captured by a linear model. Therefore, by projecting the pixels into a kernel feature space and kernelizing the linear sparse representation model, the data separability between the background and target classes will be shown to be improved, leading to a more accurate detection performance. The effectiveness of the proposed kernel sparsity model for target detection is demonstrated by experimental results on several real HYDICE hyperspectral images with real targets through ROC curves.

8390-05, Session 1

Parameter estimation for support vector anomaly detection in hyperspectral imagery

R. Meth, J. Ahn, SET Corp. (United States); A. Banerjee, R. Juang, P. Burlina, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Hyperspectral Image (HSI) anomaly detectors typically employ local background modeling techniques to facilitate target detection from surrounding clutter. Global background modeling has been challenging due to the multi-modal content that must be automatically modeled to enable target/background separation. We have previously developed a support vector based anomaly detector which does not impose an a priori parametric model on the data and enables multi-modal modeling of large background regions with inhomogeneous content. Effective application of this support vector approach requires the setting of a kernel parameter that controls the tightness of the model fit to the background data. Estimation of the kernel parameter has typically considered Type I / false-positive error optimization due to the availability of background samples, but this approach has not proven effective for

general application since these methods only control the false alarm level, without any optimization for maximizing detection. Parameter optimization with respect to Type II / false-negative error has remained elusive due to the lack of sufficient target training exemplars. We present an approach that optimizes parameter selection based on both Type I and Type II error criteria by introducing outliers based on existing hypercube content to guide parameter estimation. The approach has been applied to hyperspectral imagery and has demonstrated automatic estimation of parameters consistent with those that were found to be optimal, thereby providing an automated method for general anomaly detection applications.

8390-06, Session 2

Leveraging lidar data to aid in HSI target detection in the radiance domain

E. Ientilucci, Rochester Institute of Technology (United States); P. Kopacz, ITT Corp. Geospatial Systems (United States)

The paper discusses the approach of leveraging LiDAR data to aid in an HSI target detection application. The hyperspectral data enables one to better understand the material properties of an object. The LIDAR data enables one to define the dimensions and shape of an object and its surround (i.e., impacting illumination). It can, per pixel, describe what the geometric effects exist in the scene (i.e., solar illumination, terrain slope, and sky exposure). For this application, the detection is performed in the radiance domain. Work is also underway in implementing this technique in the reflectance domain. The algorithm / process has been implemented in the form of a plug-in GUI for ENVI. Results will be shown on both simulated and real data sets. Using very simple detection algorithms (e.g., SAM) on simulated data shows that this approach can find a single target (given a target reflectance) in both full sunlight and full shadow, simultaneously in a single pass.

8390-07, Session 2

Multisensor analysis of a simultaneously acquired LiDAR and VISNIR hyperspectral data set

P. Gader, R. Close, Univ. of Florida (United States); A. Zare, Univ. of Missouri-Columbia (United States); D. Dranishnikov, Univ. of Florida (United States)

A co-registered data set consisting of LiDAR and VISNIR hyperspectral measurements is described. Comparative detection results on a set of sixty emplaced and numerous naturally occurring targets are given. The hyperspectral and LiDAR sensors were collocated in the same aircraft. The imaged area included beaches, highways, live oak trees, grassy areas, buildings, and other natural and unnatural materials. Additionally, hundreds of in-situ spectral measurements were collected. The emplaced targets consisted of non-specular cloths attached to frames approximately one-half meter from the ground. Four different colors of cloths were used, one brown and three shades of green. There were fifteen cloths of each color: five 3 x 3 meter cloths, five 1 x 1 meter cloths, and five 1/2 x 1/2 meter cloths. Since the resolution is one meter, the large cloths should produce at least one pure pixel in the hyperspectral images, the medium cloths would be unlikely to produce a pure pixel, and the small cloths could not produce a pure pixel. The cloth targets were placed in positions such that, when imaged, they would range from completely unoccluded to partially occluded to almost completely occluded. Most of the occlusion was caused by oak trees. Thus, the data set was designed to test subpixel detection under differing levels of occlusion. A hypothesis to be tested is that the LiDAR can improve detection results by helping to detect targets that are partially occluded under trees. Detection results from human analysis as well as two different automated detection algorithms are presented.

8390-08, Session 2

Blob-level active passive data fusion for Benthic classification

J. Y. Park, H. Kalluri, A. Mathur, V. Ramnath, M. Kim, J. Aitken, V. Feygels, Optech International, Inc. (United States); G. H. Tuell, Georgia Tech Research Institute (United States)

In earlier work, we developed strategies for combining bathymetric lidar and hyperspectral data to accomplish pixel-level classifications of the seafloor. Here, we extend our algorithms to the more semantically meaningful blob level, using the mean-shift algorithm to form labeled blobs having high similarity in the feature domain, and connectivity in the spatial domain. We have also developed Bhattacharyya Distance (BD) and rule-based classifiers, and have implemented these higher-level data fusion algorithms into the CZMIL Data Processing System. Applying these new algoritms to recent SHOALS and CASI data at Plymouth Harbor, Massachussetts, we achieved improved benthic classification accuracies over those produced with either single sensor, or pixel-level fusion strategies. These results appear to validate the hypothesis that classification accuracy may be generally improved by adopting higher spatial and semantic levels of fusion.

8390-09, Session 2

Characterization of aquatic benthic reflectance using fused SHOALS and CASI airborne data and in situ spectral data

J. Aitken, J. Y. Park, M. K. Reif, M. Kim, Optech International, Inc. (United States)

Monitoring the health and extent of Submerged Aquatic Vegetation (SAV) is important because it provides important fish and wildlife habitat. Here, we report on recent work to map SAV using simultaneous airborne SHOALS and CASI systems, processed with the CZMIL Data Processing System, and constrained with in situ measurements made with handheld spectrometers. The in situ data are used to train the automated classifiers with the unique spectral reflectance of the species of interest. In the field campaign, we used two hand-held spectrometers; an above-water Analytical Spectral Devices (ASD) spectrometer and a submersible DiveSpec, both operating in the 400-1100 nm spectral range. Notably, the DiveSpec has the option of generating its own light source, eliminating the need for solar illumination, and allowing for direct reflectance measurements independent of solar and water conditions. The hand-held spectrometers were cross-calibrated at the beginning of the project, and checked periodically using a calibrated 12% reflectance panel. In this paper, we present in situ reflectance spectra for dominant aquatic vegetation types and unvegetated substrates found in Plymouth Harbor and Buttermilk Bay, MA, and present comparisons made to remotely sensed reflectance spectra extracted from SHOALS and CASI data processed in the CZMIL DPS software.

8390-10, Session 3

An automatic detection software for differential reflection spectroscopy

S. E. Yuksel, T. A. Dubroca, R. E. Hummel, P. Gader, Univ. of Florida (United States)

Recent terrorist attacks have sprung a need for a large scale explosive detector. Our group has developed differential reflection spectroscopy which can detect explosive residue on surfaces such as parcel, cargo and luggage. In short, broad band ultra-violet and visible light is shone onto a material (such as a parcel) moving on a conveyor belt. Upon reflection off the surface, the light intensity is recorded with a spectrograph (spectrometer in combination with a CCD camera). This reflected light intensity is then subtracted and normalized with the next data point collected, resulting in differential reflection spectra in the 200-500 nm range. Explosives show spectral finger-prints at specific wavelengths, for example, the spectrum of 2,4,6, trinitrotoluene (TNT) shows an absorption edge at 420 nm. Additionally, we have developed an automated software which detects the characteristic features of explosives. One of the biggest challenges for the algorithm is to reach a practical limit of detection. In this study, we introduce our automatic detection software which is a combination of principal component analysis and support vector machines. Finally we present the sensitivity and selectivity response of our algorithm as a function of the amount of explosive detected on a given surface.

8390-11, Session 3

A multitemporal analysis approach for land cover analysis in support of nuclear incident response

S. Sah, J. van Aardt, D. McKeown, Rochester Institute of Technology (United States)

Remote sensing can be used to rapidly generate land use maps for assisting emergency response personnel with resource deployment and impact assessment. In this study we focus on building accurate land cover maps to map the impacted area in the case of a nuclear release. The main aim is to build an automated software tool that uses multi-spectral satellite imagery to produce a nuclear ingestion pathway information product within few hours after data collection. The proposed methodology involves integration of results from two different approaches to increase classification accuracy. The first step is building a coarse-scale land cover map from freely available, high temporal resolution MODIS data using a time-series approach. In case of a nuclear accident, commercial satellites such as RapidEye or IKONOS can acquire images of the affected area. Land use maps from the first step will serve as the pre-event classification training data for supervised classification of high spatial resolution, but low temporal resolution images. Preliminary results, based on both supervised and unsupervised classifications using maximum likelihood, spectral angle mapper, and ISODATA methods, showed an accuracy of over 80% when compared with GIS data sets from New York State. The data used included RapidEye scenes over Nine Mile Point Nuclear Power Station (Oswego, NY). We wish to augment this approach with the multi-temporal MODIS data for improved classification accuracy. Results will be presented at the conference.

8390-12, Session 3

Man-made activity detection in hyperspectral imaging: performance analysis of different algorithms

R. Enbar, G. Sharon, S. R. Rotman, Ben-Gurion Univ. of the Negev (Israel); A. Schlamm, D. Messinger, Rochester Institute of Technology (United States)

In this paper, we consider detecting man-made objects in natural images. We divide the image into tiles; we consider a variety of metrics and correlate them to the presence of man-made targets. To quatify the metric, we extend a method of implanting targets and evaluating the resulting ROC (Receivor Operating Characteristic) curves. We rank previously reported algorithms plus develop new ones in this paper.

8390-13, Session 3

Measurements of laminar flames with mid- and long-wave infrared imaging Fourier-transform spectrometers

M. Rhoby, K. C. Gross, Air Force Institute of Technology (United States)

A laboratory is being stood up for determining the performance of imaging Fourier-transform spectrometry (IFTS) for quantifying smokestack effluents and flare combustion efficiencies. Both a Telops Hyper-Cam mid-wave IR (1.5-5.5 µm) IFTS and a long-wave IR (8-12 µm) IFTS have measured the laminar flame and post-combustion plume from a Hencken burner. Methane (CH4), ethane (C2H6), and ethylene (C2H2) gases have been studied and spatially-resolved spectra have been collected under various fuel-to-air ratios (FAR) and mass flow rates (MFR). The influence of FAR and MFR on the measured spectra will be discussed. Simple models are being developed to interpret the measured spectra so that combustion efficiencies can be determined. The Hencken burner produces a quasi-harmonic intensity flicker, and this introduces artifacts in the measured spectra. The influence of the harmonic flicker on instrument line shape will be discussed and methods for mitigating its effects will be described.

8390-14, Session 3

EO-1 Hyperion spectral time series for vegetation assessment and system comparison

P. K. E. Campbell, E. M. Middleton, NASA Goddard Space Flight Ctr. (United States)

Satellite remote sensing is essential for monitoring vegetation physiology, phenology and spatial variation, to assess the impact of terrestrial ecosystems on the dynamics of carbon fluxes and improve our understanding of the underlying factors. High spectral resolution measurements (≤10 nm, 400-2500 nm) provide an efficient tool for synoptic evaluation of many of the factors significantly affecting the ability of the vegetation to sequester carbon and to reflect radiation, due to changes in vegetation chemical and structural composition.

This study focuses on the analysis of Earth Observing-1 (EO-1) Hyperion data in comparison to CO2 flux estimates at a number of LTER and/or FLUXNET sites, that represent major vegetation types (e.g., hardwood forest, grassland, evergreen forest, savanna, rain forest, desert). We are demonstrating the commonality of specific spectral bio-indicators across all sites that are associated with vegetation function. The spectral indices express seasonal dynamics induced by the variations in temperature, nutrient and moisture availability. EO-1 Hyperion seasonal composites were assembled and the radiance data were corrected for atmospheric effects. Spectral bio-indicators were computed from surface reflectance spectra collected in the flux tower footprints and compared to field flux tower measurements (e.g., CO2 flux, µmol m-2 s-1). Spectral signatures significantly differed based on vegetation type and site specific phenology. Nevertheless, our preliminary results suggest a strong correlation between CO2 flux and a small set of bio-indicators associated with pigment content. These findings are compared to simulations of results, expected to be obtained from Operational Land Imager (OLI) and Sentinel-2 visible/near-infrared and short-wave infrared (VNIR/SWIR) data.

8390-15, Session 3

Methods for estimating forest stem volumes by tree species using digital surface model and CIR images taken from light UAS

H. Salo, I. J. Pellikka, V. Tirronen, Univ. of Jyväskylä (Finland); S. Tuominen, A. Balazs, Finnish Forest Research Institute (Finland); J. Heikkilä, PIEneering Ltd. (Finland); H. Saari, VTT Technical Research Ctr. of Finland (Finland)

Sufficiently overlapping images can be used to construct stereophotometrically a Digital Surface Model (DSM). Instead of using LiDAR and additional multiband imagery a Color Infrared (CIR) camera

mounted to a light UAV is used to acquire highly overlapping images of the target forest area. Because of the high degree of overlap of the images the DSM of target area can be generated. The used CIR camera was a modified RICOH GR Digital III. The NIR cutoff filter of the RICOH camera was removed and a Schott color glass long pass filter OG515 was used instead of it. This changes the standard RGB wavelength bands to green (about 500 - 600 nm), red (about 600 - 700 nm) and NIR bands (about 700 - 1000 nm). A part of the target area was imaged also with a UAV hyperspectral camera in the wavelength range 500 - 900 nm at 15-30 nm spectral resolution. The study area is the educational forest of Evo in the Southern Finland. Acquired imagery covers hundreds of hectares of various Finnish forest types including known forest stands. The aim of this study is to investigate methods for estimating stem volumes by tree species and to compare two different methods. A popular k-NN method is compared to multiphase method that consists of dividing estimated total tree stem volume by species using a few detected and classified individual trees. The multiphase method uses support vector machines for estimating the total tree volume and for classifying detected trees to species. Used spectral and spatial feature extraction methods are also presented.

8390-16, Session 4

DIRSIG 5: core design and implementation

A. A. Goodenough, S. D. Brown, Rochester Institute of Technology (United States)

The Digital Imaging and Remote Sensing Image Generation (DIRSIG) model has been developed at the Rochester Institute of Technology (RIT) for over two decades. The last major update of the model, DIRSIG 4, built on an established, first-principles, multi- and hyper-spectral scene simulation tool. It introduced a modern and flexible software architecture to support new sensor modalities and more complex and dynamic scenes. Since that time, the needs of the user community have grown and diversified in tandem with the computational capabilities of modern hardware. Faced with a desire to model more complex, multi-component systems that are beyond the original intent and capabilities of an aging software design, a new version of DIRSIG, version 5, is being introduced to the community.

This paper describes the core of DIRSIG 5 that is responsible for linking the disparate sensor, scene, and environmental models together, spatially, temporally, and parametrically. The spatial relationships are governed by a planet-centric universe model encompassing a whole globe digital elevation and optical property model, the scene model(s), globally varying atmospheric models, and a space model. Temporal relationships are driven by a formal modeling and simulation architecture based on approaches used in engineering and biological sciences to model highly dynamic and interactive systems. Finally, the parametric interfaces are described by a universal data model that facilitates scripting, inter-dependent properties and user interface construction. The design of these components will be presented along with specific module implementation details. These simulation tools will be used to demonstrate some of the new capabilities and applications of DIRSIG 5.

8390-17, Session 4

Parking lot process model incorporated DIRSIG scene simulation

J. Sun, D. Messinger, Rochester Institute of Technology (United States)

The Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool is a first principles-based synthetic image generation model, developed at the Rochester Institute of Technology (RIT) over the past 20+ years. By calculating the sensor reaching radiance between the bandpass 0.2 to 20µm, it produces multi or hyperspectral remote sensing images. By integrating independent first principles based sub-models, such as MODTRAN, DIRSIG generates a representation of what a sensor would see with high radiometric fidelity. In order to detect temporal changes in a process within the scene, currently the effort is devoted to enhance the capacity of DIRSIG by incorporating process models. Parking lot process models are interesting to many applications. To build a parking lot process model for RIT campus, an experiment is set up to record the distribution of cars in several parking lots on RIT campus over one weekday by taking photos every five minutes. The image data are processed to extract the information of parking time, parking duration and parking location for each car coming into the parking lot. In order to take advantage of existing parking lot models, the extracted information of the experiment is compared with the output data from PARKAGENT which simulates the behavior of each driver in a spatially explicit environment. Then the input parameters of PARKAGENT could be optimized to better represent the dynamic process of the parking lot. The built parking lot process model could be generalized to describe the activity of other parking lots of different areas.

8390-18, Session 4

Geo-accurrate primitive extraction from three-dimensional, image-derived point clouds

D. R. Nilosek, C. Salvaggio, Rochester Institute of Technology (United States)

A methodology is proposed for automatically extracting geometric primitives of buildings in a scene from a three-dimensional point cloud derived from multi-view depth extraction techniques. These primitives are placed together to form a primitive building model. By exploring the information provided by the two-dimensional images and the three-dimensional point cloud and the relationship between the two, automated methods for primitive extraction are presented. The structure from the three-dimensional point cloud is combined with the spatial and color information from the imagery to segment buildings from the point cloud, and remove points caused by vegetation and shadows. The geometric primitive extraction is a RANSAC-based approach which extracts basic geometry from the segmented point cloud. Using the inertial measurement unit (IMU) data that accompanies the imagery, the geometry is projected into a world-coordinate system so the model can be used with GIS software. This work uses imagery collected by the Rochester Institute of Technology's Digital Imaging and Remote Sensing Laboratory's WASP sensor platform. The data used was collected over the RIT campus and downtown Rochester. Multiple target buildings have their component geometric primitives extracted and used to form primitive three-dimensional model geometry.

8390-19, Session 4

Evaluation of image collection requirements for 3D reconstruction using phototourism techniques on sparse overhead data

E. Ontiveros, Rochester Institute of Technology (United States)

Phototourism is a burgeoning field that uses collections of ground-based photographs to construct a three-dimensional model of a tourist site, using computer vision techniques. These techniques capitalize on the extensive overlap generated by the various visitor-acquired images from which a three-dimensional point cloud can be generated. From there a facetized version of the structure can be reconstructed. Remotely sensed data tends to focus on nadir or near nadir imagery while trying to minimize overlap in order to achieve the greatest ground coverage possible during a data collection. A workflow is being developed at the Rochester Institute of Technology (RIT) that utilizes these phototourism techniques, which exploits dense image coverage of a small region or object, and applies them to remotely-sensed imagery, which involves sparse data coverage of a much larger area. In addition to this, RIT has planned and executed a high-overlap image collection, using the RIT WASP system, to study the requirements needed for such three-dimensional reconstruction efforts. While the collection was extensive, the intention was to find the minimum number of images and frame overlap needed to generate quality point clouds. This paper will discuss the image data collection effort and what it means to generate and evaluate a quality point cloud for reconstruction purposes.

8390-20, Session 5

WorldView-2 and the evolution of the DigitalGlobe Remote Sensing Satellite Constellation

N. T. Anderson, G. B. Marchisio, DigitalGlobe, Inc. (United States)

Over the last decade DigitalGlobe has built and launched a series of remote sensing satellites with steadily increasing capabilities: QuickBird, WorldView-1, and WorldView-2. Today this constellation acquires over 2 million km2 of imagery every day. This paper presents the configuration and performance capabilities of each of these satellites with emphasis on the unique spatial and spectral capabilities of WorldView-2. WorldView-2 employs high precision star tracker and inertial measurement units to achieve a geolocation of 5m, CE90. The native resolution of WorldView-2 is 0.5m GSD in the panchromatic band and 2m GSD in 8 multi-spectral bands. Four of the multi-spectral bands match those of the Landsat series of satellites; four new bands enable novel and expanded applications. We are rapidly establishing and refreshing a global VHR 8-band multi-spectral image data base. Control moment gyros improve collection capacity and also provide the agility to capture multi-angle sequences in rapid succession.

These capabilities translate into a rich combination of image features that can be exploited to develop enhanced monitoring solutions. Algorithms for interpretation and analysis can leverage: 1) broader and more continuous spectral coverage at 2m resolution; 2) textural and morphological information from the 0.5m panchromatic band; 3) ancillary information from stereo and multi-angle collects, including high precision digital elevation models; 4) frequent revisits and time series collects; and 5) the global reference image archives. We introduce the topic of creative fusion of image attributes, as this provides a unifying theme for many of the papers in this special WorldView-2 session.

8390-21, Session 5

Improving the automated detection of refugee/IDP dwellings using the multispectral bands of the WorldView-2 satellite

T. Kemper, European Commission Joint Research Ctr. (Italy); M. Jenerowicz, Space Research Ctr. (Poland); M. Pesaresi, P. Soille, European Commission Joint Research Ctr. (Italy)

Globally the number of refugees and Internal Displace People (IDP) is on the rise, pushed lately by the food crisis at the horn of Africa. In such emergency situations, it is crucial to monitor the number people in a camp in order to provide the right amount of relief. Also in long term camps update on the number of people in camps needs to be checked in order to improve the aid efficiency. Different studies have described how to use very high resolution satellites to count the number of dwellings (Giada et al. 2003, Lang et al. 2010, Jenerowicz et al. 2010, Kemper et al. 2011). Most of these studies relied on the use of the panchromatic channel, sometimes using vegetation indices to separate vegetation from dwellings.

Jenerowicz et al. (2011) demonstrated that the usage of the additional spectral bands of WV-2 improved the accuracy of the estimations. The paper builds on these ideas and exploits the spectral bands more systematically.

8390-22, Session 5

Using WorldView-2 Vis-NIR MSI imagery to support land mapping and feature extraction using normalized difference index ratios

A. Wolf, Ball Corp. (United States)

Multispectral imagery (MSI) provides information to support decision making across a growing number of private and industrial applications. Among them, land mapping, terrain classification and feature extraction rank highly in the interest of those who analyze the data to produce information, reports, and intelligence products.

The 8 nominal band centers of WorldView 2 allow us to use non-traditional means of measuring the differences which exist in the features, artifacts, and surface materials in the data, and we are able to determine the most effective method for processing this information by exploiting the unique response values within those wavelength channels. The difference in responses across select bands can be sought using normalized difference index ratios to measure moisture content, indicate vegetation health, and distinguish natural features from man-made objects.

The focus of this effort is to develop an approach to measure, identify and thre-shold these differences in order to establish an effective land mapping and feature extraction process germane to WorldView 2 imagery.

8390-23, Session 5

Mapping urban vegetation cover using WorldView-2 imagery

F. Cavayas, Y. Ramos, A. Boyer, Univ. de Montréal (Canada)

There are clear indications that densification of built-up areas within cities and new developments in their outskirts, in conjunction with urban population activities, are at the origin of climate changes at the local level and have a direct impact on air and water quality. Densification of the vegetation cover, especially trees, is often mentioned as one of the most important means to mitigate the impacts of climate changes and to improve the quality of the urban environment. Decision making on vegetation cover densification presupposes that urban planners and managers know exactly the actual situation in terms of spatial distribution of that cover including vegetation types and biomass. However, in many cities, inventories of vegetation cover are usually absent. This study examines the feasibility of an automatic system for vegetation cover inventory and mapping in urban areas based on WorldView-2 imagery. The city of Laval, Canada, was chosen as the experimental site. The principal conclusions are as follows: a) conversion of digital counts to ground reflectances is a crucial step in order to fully exploit the potential of WV-2 images for mapping vegetation cover and recognizing vegetation classes; b) the combined use of NDVIs computed using the three infrared available bands and the red band provides an accurate means of differentiating vegetation cover from other land covers; c) it is possible to separate trees from other vegetation types even in dense urban areas using segmentation algorithms; e) the panchromatic channel is very helpful for improving the accuracy of vegetation cover maps and discriminating certain tree species.

8390-100, Session 5

Automating nearshore bathymetry extraction from wave motion in satellite optical imagery

S. Mancini, National Geospatial-Intelligence Agency (United States); R. C. Olsen, Naval Postgraduate School (United States); R. Abileah, jOmegak (United States)

Nearshore depths for Waimanalo Beach, HI are extracted from optical imagery, taken by the WorldView-2 satellite on 31 March 2011, by means of automated wave kinematics bathymetry (WKB). This technique uses linear gravity wave theory, and the inverse relationship between wave velocity and water depth. Two sets of three sequential images taken at intervals of about 10 seconds are used for the analyses. Water depths are calculated using a computer program that registers the images, estimates the currents, and then uses the linear dispersion relationship for surface gravity waves to estimate depth. Depths are generated from close to shore out to about 20 meters depth. Comparisons with SHOALS LIDAR bathymetry values show WKB depths are accurate to about half a meter, with R2 values of 90%, and are frequently in the range of 10-20 percent relative error for depths ranging from 2-16 meters.

8390-25, Session 6

A LWIR hyperspectral imager using a Sagnac interferometer and cooled HgCdTe detector array

P. G. Lucey, T. Williams, Univ. of Hawai'i (United States); J. Hinrichs, Spectrum Photonics, Inc. (United States)

LWIR hyperspectral imaging with high sensitivity is typically accomplished using spectrographs that require cooling at least portions of the optics, and often require low background specialty arrays. Interferometry offers an alternative that can provide high sensitivity without the need to cool the optics, and can use conventional LWIR arrays and cameras. In previous years we examined the theoretical performance of such a sensor; we have now obtained extensive laboratory test data and some field test data using an uncooled Sagnac interferometer and a Sofradir HgCdTe camera. Peak signal to noise ratios well over 1000 are obtained at frame rates of 233 Hz at 10 wavenumber resolution. Even at this rate short integrations are required, suggesting high quality data can be obtained at frames rates approaching 1000 Hz. The Sagnac arrangement is optimized for pushbroom data acquisition making this technology attractive for relatively small UAV's.

8390-26, Session 6

A compact LWIR hyperspectral system employing a microbolometer array and a variable gap Fabry-Perot interferometer employed as a Fourier transform spectrometer

P. G. Lucey, Univ. of Hawai'i (United States); J. Hinrichs, J. Akagi, Spectrum Photonics, Inc. (United States)

We previously demonstrated a Fourier transform spectrometer (FTS) using a Fabry-Perot interferometer with the gap between its partially reflecting layers varying orthogonal to the optical axis to produce a gradient in optical path difference at a detector. The gradient produces a period fringe pattern that can be analyzed with standard FTS techniques. Experiments in the visible and IR demonstrated the feasibility of this method for spectroscopy. We have now packaged this system as an LWIR hyperspectral system and have obtained test data on a variety of spectrally variable targets in both the far and near field. The sensor is compact enough to be suitable for handheld use.

8390-27, Session 6

Spectral polarimetric imaging in the infrared

D. B. Chenault, J. L. Pezzaniti, J. S. Harchanko, Polaris Sensor Technologies, Inc. (United States)

Multispectral instrumentation has opened up new areas for exploitation of natural phenomena for defense and homeland security applications. In a similar way, polarization imaging is opening up new signatures that provide additional information to conventional imaging systems. We report on the development of several sensors that are relatively compact and portable that combines imaging with spectral and polarization sensitivity in the short wave IR (SWIR), mid wave infrared (MWIR), and long wave infrared (LWIR). These sensors use a variety of multiplexing techniques that enable fast acquisition of spatial, polarimetric, and spectral data in a part of the spectrum that has heretofore had relatively little imaging data collected in the spectral polarimetric domain. We describe the sensors, data collection activities, and results with these sensors.

8390-28, Session 6

Snapshot hyperspectral fovea vision system

J. M. Kriesel, N. Gat, Opto Knowledge Systems, Inc. (United States); S. Nagaraj, V. Swaminathan, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

The development and demonstration of a new snapshot hyperspectral sensor will be presented. The system is a significant extension of the 4DIS concept, which resolves all four dimensions of hyperspectral imaging data (2D spatial, spectral, and temporal) in real-time. The new sensor, dubbed "4x4DIS" uses a single fiber optic reformatter that feeds into 4 separate, miniature visible to near-infrared (VNIR) imaging spectrometers, for a factor of 4 better spatial resolution than previous systems.

Full data cubes are captured in each frame period without scanning. The current system operates up to 30 Hz (ie.,30 cubes/s), has 300 spectral bands from 400 to 1000 nm (~2 nm resolution), and a spatial resolution of 44 x 40 pixels. An additional 1.4 Megapixel color video camera provides scene context and effectively sharpens the spatial resolution of the hyperspectral data.

Essentially, the 4x4DIS provides a 2D spatially resolved grid of 44x40 = 1760 separate spectral measurements every 33 ms, which is overlaid on the detailed spatial information provided by the color context camera. The system can be operated in a "spectral fovea" mode, in which the 4x4DIS system uses narrow field of view optics, and is cued by the wider field of view context camera.

Unlike other hyperspectral snapshot schemes, which require intensive computations to deconvolve the data (e.g., Computed Tomographic Imaging Spectrometer), the 4x4DIS requires only linear remapping, making it appropriate for real-time operation. The system has a range of applications including biomedical imaging, missile defense, and ground based remote sensing.

8390-29, Session 6

Combination of a near-infrared, dispersive spectral imager and of a visible static Fourier transform spectral imager

Y. Ferrec, ONERA (France)

Hyperspectral imaging is a more and more widespread tool, especially for environmental monitoring or archeological prospecting. For such applications, there is a need for spectral imagers easy to operate, especially on UAV, and so without a stabilization platform.

Most of current hyperspectral imagers are dispersive ones. It means that a front lens forms the image on the scene in an intermediate plane, where a slit selects only a line of the image. This line is then dispersed on the focal plane array by a prism or a grating. Thus, registering the consecutive line images needs an inertial measurement unit, and a photogrammetric software. On the other hand, for spectral imagers based on 2D imagers, like imaging static Fourier transform spectrometers, image registration can be done from the images themselves. However, they often need much more along track pixels than the final numbers of spectral bands.

We suggest merging these two kinds of spectral imagers, by cutting the slit in a mirror oriented at about 45 degrees with respect to the optical axis. The reflected light is then sent toward the static Fourier transform spectral imager. Thus, the two spectrometers can be exactly co-registered, since the position of the slit is tagged on each frame of the FT spectrometer.

We propose to illustrate this concept by a dual-band spectral imager, based on a grating spectrograph operating in the near infrared domain ([0.9μm;1.7μm]) and on a static FT spectral imager operating in the visible domain ([0.4μm;0.9μm]), both using commercially available focal plane arrays. We will present the preliminary design of this hyperspectral imager, and an evaluation of the expected geometric and radiometric performances.

8390-30, Session 7

High-speed atmospheric correction for spectral image processing

T. Perkins, S. M. Adler-Golden, Spectral Sciences, Inc. (United States); P. Cappelaere, Vightel Corp. (United States); D. Mandl, NASA Goddard Space Flight Ctr. (United States)

Land and ocean data product generation from visible-through-shortwave-infrared multispectral and hyperspectral imagery requires atmospheric correction or compensation, that is, the removal of atmospheric absorption and scattering effects that contaminate the measured spectra. We have recently developed a prototype software system for automated, low-latency, high-accuracy atmospheric correction based on a C++-language version of the Spectral Sciences, Inc. FLAASH(TM) code. In this system, pre-calculated look-up tables replace on-the-fly MODTRAN® radiation transport calculations, while the portable C++ code enables parallel processing on multicore/multiprocessor computer systems. The initial software has been installed on the Sensor Web at NASA Goddard Space Flight Center, where it is currently atmospherically correcting new data from the EO-1 Hyperion and ALI sensors. Computation time is around 10 s per data cube per processor. Further development will be conducted to implement the new atmospheric correction software on board the upcoming HyspIRI mission's Intelligent Payload Module, where it would generate data products in near-real time for Direct Broadcast to the ground. The rapid turn-around of data products made possible by this software would benefit a broad range of applications in areas of emergency response, environmental monitoring and national defense.

8390-31, Session 7

Atmospheric compensation for WorldView-2 satellite and in-water component retrieval

J. A. Concha, A. Gerace, Rochester Institute of Technology (United States)

In the present work, the WorldView-2 (WV2) capability for retrieving Case 2 water components is analyzed. The WV2 sensor characteristics, such as a 11-bit quantization, 8 bands in the VNIR and high Signal-to-Noise Ratio (SNR) make WV2 potentially suitable for a retrieval process. In the Case 2 water problem, the sensor-reaching signal due to water is very small when compared to the signal due to the atmospheric effects. Therefore, adequate atmospheric compensation becomes an important first step to accurately retrieving water parameters. The problem becomes more difficult when using multispectral imagery as there are typically only a handful of bands suitable for performing atmospheric compensation. In this work, we develop atmospheric compensation techniques designed specifically for the WV2 satellite, enabling it to be used for water constituent retrieval in both deep and shallow water. A look-up-table (LUT) methodology is implemented to retrieve the water parameters Chlorophyll, Suspended Materials, Colored Dissolved Organic Matter, bathymetry, bottom type and water clarity for a simulated case study. The in-water radiative transfer code HydroLight is used to simulate reflectance data in this study while the MODTRAN code is used to simulate atmospheric effects. The resulting modeled sensor-reaching radiance can be sampled to a WV2 sensor model to simulate WV2 image data. This data is used to test the described methodology. Finally, a sensitivity analysis is performed to evaluate how sensitive the retrieval process is to adequate atmospheric compensation.

8390-32, Session 7

An automatic atmospheric compensation algorithm for very high-spatial resolution imagery

F. Pacifici, DigitalGlobe, Inc. (United States)

There are several techniques published in the literature aimed at automatically characterizing the atmospheric effects on satellite imagery. However, multi- or hyper-spectral data is typically used, generally including short-wave infra-red wavelengths.

When multi-spectral data with only visible and near infra-red wavelengths or panchromatic images are used (such as the one provided by DigitalGlobe), alternative methods often based on radiative transfer models can be developed. However, these techniques rely on educated assumptions on the status of the atmosphere, location, day of the year, etc..

This talk illustrates the results produced by a fully automated method to atmospherically compensate very high spatial resolution multi-spectral and panchromatic imagery.

The method has been validated on a set of 12 QuickBird scenes acquired over various locations in the U.S.A. where calibrated tarps were deployed. This set of tarps included four 20-meter-square spectrally-flat targets having nominally 3.5, 22, 34, and 52% reflectance in the visible through NIR spectral region.

Further, a two year image time-series over Longmont, CO, was used to analyze the stability of the proposed method under different weather and viewing conditions. The data set was composed by more than 150 multi-spectral and panchromatic QuickBird, WorldView-1, and WorldView-2 images acquired between 2009 and 2011. Two sets of bidirectional reflectance distribution function of asphalt and concrete (about 20% and 40% reflectance, respectively) have been acquired during the summer of 2011 and used as reference.

8390-33, Session 7

Atmospheric correction of the CASI hyperspectral image using the scattering angle by the direct solar beam

M. Kim, J. Y. Park, J. Aitken, Optech International, Inc. (United States)

Airborne hyperspectral data over the coastal zone are significantly perturbed by the water surface effect. Specifically, the water surface reflects downwelling radiance from all sources above the sea, adding nuisance radiance to the signal of interest in the downward looking sensor. One popular technique to remove this nuisance radiance is the dark-pixel method wherein the reflectance in a near-IR spectral channel (around 740 nm) is assumed to be zero. In high resolution coastal remote sensing this method may be problematic as turbid and very shallow waters often contain signals of interest in this wavelength region. Consequently, adoption of the zero-reflectance assumption can adversely affect the processing of other pixels, leading to over correction and pixels with negative reflectance. As an alternative, we have implemented in the CZMIL Data Processing System a robust pixel-by-pixel corrector using the bi-directional reflectance angles for each sea surface pixel, computed using the navigation data, viewing geometry, and solar ephemeris. Since the scattering angle of the direct solar beam reflected into the sensor field-of-view is computed using geometry only, it is completely free from the possible trouble met by the dark-pixel approach.

8390-34, Session 7

A comparison of QUAC and covariance equalization for atmospheric, solar angle, and look angle compensation in airborne multi- and hyperspectral SWIR target detection

M. K. Yetzbacher, E. C. Allman, B. J. Daniel, A. P. Schaum, U.S. Naval Research Lab. (United States)

Scene-based atmospheric correction algorithms can greatly enhance real-time target detection capability of airborne multispectral/hyperspectral imagery. Both the quick atmospheric correction (QUAC) and covariance equalization (CE) are scene-based algorithms that have been applied to SWIR data to improve the performance of automated target detection in airborne hyperspectral imagery. This study compares QUAC and CE effects on detection performance for several types of targets in imagery collected in desert, wooded, and urban environments. Variants of the CE algorithm are also investigated. Quantitative comparisons are made using receiver operating characteristic (ROC) curves generated by several standard target detection algorithms. ROC curve dependence on the number of bands for particular targets is given; comparisons are made for >100-band hyperspectral data down to 3-band multispectral data. Also studied is performance dependence on scene variation and its degradation with reduced spectral resolution.

8390-35, Session 7

Atmospheric correction of short-wave hyperspectral imagery using a fast, full-scattering 1DVar retrieval scheme

J. Thelen, S. Havemann, J. P. Taylor, Met Office (United Kingdom)

Here, we propose an alternative method to existing atmospheric correction schemes to retrieve the surface reflectance spectra from shortwave hyperspectral imagery obtained from air/space-borne platforms, such as AVIRIS or Hyperion EO1. This new scheme consists of a fast radiative transfer code, based on empirical orthogonal functions (EOFs), in conjunction with a 1D-Var retrieval scheme.

In order to be able to treat Rayleigh scattering and scattering by water droplets, ice crystals and aerosols accurately, an exact line-by-line, scattering code based on Legendre polynomials has been included in the fast radiative transfer code.

This scheme has several advantages. Firstly, it allows for a highly accurate treatment of the radiative properties which should result in more accurate retrievals of the surface reflectances. Secondly, the whole spectral interval 0.4 microns to 2.5 microns, used by several hyperspectral, shortwave imagers, can be retrieved without having to neglect the absorption features due to H2O and OH. Thirdly, it allows for the simultaneous retrieval of the surface properties and the atmospheric profiles, such as temperature, humidity, aerosols and trace gases. Finally, background and instrument errors are also being considered via the use of error covariance matrices.

This approach was successfully tested using hyperspectral images taken by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Hyperion on board of the Earth Observatory 1 (EO-1)

8390-36, Session 8

Collection and quality control of spectral signatures in the field

B. Curtiss, ASD, Inc. (United States)

Field spectral signatures are commonly collected in conjunction with remote sensing campaigns. Unfortunately, the lack of sufficient metadata associated with campaign-specific spectral signatures often makes it difficult for others to utilize them for their own applications. The first step in improving the utility of field collected spectral signatures is achieved by establishing fully documented procedures that minimize controllable error sources. A major source of error when collecting field spectral signatures is the variability of solar illumination. By periodically monitoring a static reference panel it is possible to both characterize the variance in solar illumination during collection as well as to correct collected spectra. In addition, recent advances in instrument sensitivity greatly reduce the time required to collect high quality spectra that in turn reduces the magnitude of potential errors associated with changes in solar illumination. Since libraries of field spectral signatures are commonly used to analyze remotely sensed imagery, it is important that field collection is performed at a relevant spatial scale and with illumination and viewing geometry that is similar to that for the image collection. This is particularly true of vegetation since the observed spectral signature is the result of the complex interaction of multiple illumination sources (i.e. direct sunlight, sky illumination and light scattered off other elements in the scene), canopy architecture and the reflectance properties of the individual elements within the canopy. Several field collection case studies that demonstrate these issues along with suggested field collection approaches that minimize these sources of error will be presented.

8390-37, Session 8

Spectral library generation for hyperspectral archaeological validation

K. Canham, W. Middleton, D. Messinger, N. G. Raqueno, Rochester Institute of Technology (United States)

Fractional abundance maps have been produced from Hyperion hyperspectral data over Oaxaca, Mexico, by applying a new spatially adaptive spectral unmixing algorithm. The goal of this research is to produce land-use maps for aiding archaeologists studying the Zapotec civilization. However, to correlate the fractional abundance maps generated from the HSI image processing, a relationship between the known materials located in Oaxaca, Mexico, and the spectral profiles of these materials must be established. A field campaign during December 2011, (the dry season in Oaxaca) took place for the explicit task of obtaining spectral profiles of the most common materials found in the region. Ground-truth information was collected for three Oaxaca valleys (Tlacalula, Yanhuitlan, and Ycuitla). Common materials and associated regions were recorded and material samples were collected at many of these locations. Laboratory reflectance spectral profiles of the collected material samples are measured after the field campaign using a FieldSpec Pro. Wavelength ranges of the FieldSpec Pro spanned 350-2500nm matching that of the hyperspectral imagery collected from the Hyperion sensor on board the EO-1 satellite. GIS maps of three valleys in Oaxaca, Mexico, are used to identify where these samples were collected and correspond to the laboratory measured material samples. The spectral library entries obtained correspond to bare soils, senescent agricultural vegetation, senescent natural vegetation, and terra cotta tile.

8390-38, Session 8

Point source emissions mapping using airborne visible/infrared imaging spectrometer data

A. K. Thorpe, D. A. Roberts, Univ. of California, Santa Barbara (United States); P. E. Dennison, The Univ. of Utah (United States); E. S. Bradley, C. C. Funk, Univ. of California, Santa Barbara (United States)

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) measures reflected solar radiation in the shortwave infrared and has been used to map methane (CH_4) using both a radiative transfer (Roberts et al., 2010) and band ratio technique (Bradley et al., 2011). However, these methods are best suited to water bodies with high sunglint and cannot be applied to terrestrial scenes. In this study, a cluster-tuned matched filter algorithm

originally developed by Funk et al. (2001) for synthetic thermal data was used for gas detection over more heterogeneous backgrounds.

This approach permits mapping of CH4, CO2, and N2O trace gas emissions in multiple AVIRIS scenes for terrestrial and marine targets. At the Coal Oil Point marine seeps offshore of Santa Barbara, CA, strong CH4 anomalies were detected that closely resemble results obtained using the band ratio index. CO2 anomalies were mapped for a number of fossil-fuel power plants, while multiple N2O and CH4 anomalies were present at the Hyperion wastewater treatment facility in Los Angeles, CA. Nearby, smaller CH4 anomalies were also detected immediately downwind of hydrocarbon storage tanks and centered on a flaring stack at the Inglewood Gas Plant.

Improving these detection methods might permit gas detection over large regions, for example fugitive CH4 emissions from damaged natural gas pipelines or hydraulic fracturing. Further, this technique could be applied to additional trace gasses with distinct absorption features and data from planned instruments such as AVIRISng, the NEON Airborne Observation Platform (AOP), and the HyspIRI VSWIR satellite.

8390-39, Session 8

Spectroscopic remote sensing for material identification, vegetation characterization, and mapping

R. F. Kokaly, U.S. Geological Survey (United States)

The identification of materials by measuring and analyzing their reflectance spectra is a powerful method used in analytical chemistry. Airborne and space-based imaging spectrometers allow material distributions to be detected and mapped across the landscape. Robust methods are needed to fully exploit the information content in imaging spectrometer data. Careful processing of laboratory, field, and remote sensing data is required to produce high-quality spectra which can be compared with spectral standards for identifying the composition of materials based on their reflectance properties. In this paper, a software package called PRISM (Processing Routines in IDL for Spectroscopic Measurements) is described. Among its many functions, PRISM contains routines for spectral data management, processing, and analysis, including storage of spectra in database files, importation of field spectra, correction of field spectra to absolute reflectance, arithmetic operations on spectra, and calibration of imaging spectrometer data to reflectance. Custom functions include interactive continuum removal and comparison of absorption features and spectral analysis with the Material Identification and Characterization Algorithm (MICA). MICA works by identifying and mapping materials using spectral analysis of absorption features in reflectance spectra. PRISM has been used to calibrate image cubes and map materials for the full-country coverage of Afghanistan in 2007 with HyMap. Applications of PRISM and MICA to this data set for mineral detection will be presented, along with applications to AVIRIS data for detecting oil contamination and characterizing vegetation degradation and recovery in oiled areas. The PRISM software will be available to the general public from the U.S. Geological Survey.

8390-92, Poster Session

Application of probabilistic graphical models for feature-based detection of invasive alien plants from WorldView-2 satellite imagery

W. M. Dlamini, Swaziland National Trust Commission (Swaziland)

This study describes the use of probabilistic graphical models, in particular Bayesian networks (BN), for the detection of four invasive alien plants, Chromolaena odorata, Caesalpinia decapitala, Eucalyptus grandis and Pinus patula from 8-band Worldview-2 satellite imagery acquired over 2 characteristically different sites, a nature reserve and an urban area, in Swaziland. The main objective of this study was to evaluate and apply the efficacy of the very high resolution 8-band imagery for invasive alien plant detection using BN models. In this paper, structural learning approaches, including those based on feature subset selection, were adapted to induce six augmented BN classifiers (general Bayesian network, naïve Bayes, tree-augmented naïve Bayes - TAN, selective tree-augmented naïve Bayes, selective tree augmented naive Bayes with node discarding, forest augmented naïve Bayes, selected forest augmented naïve Bayes and selective forest augmented naive Bayes with node discarding) in order to detect the four species. Although all the BNs produced very accurate solutions for all the species, the selective augmented BN models were relatively superior and always selected the useful bands, in particular the red-edge, near infrared 2 and yellow bands, with lower computer processing times. Results varied depending on the characteristics of both the locality and species investigated. Moreover, the significance of the subset of variables selected along with the comprehensibility of probabilistic graphical models point to their potential usefulness and applicability for plant species detection and general feature detection from high spatial and spectral resolution satellite imagery.

8390-93, Poster Session

DSP design for real-time hyperspectral target detection based on spatial-spectral information extraction

W. Yang, B. Zhang, L. Gao, Y. Wu, Ctr. for Earth Observation and Digital Earth (China)

Military target detection is an important application of hyperspectral remote sensing. It highly demands real-time or near real-time processing. However, the massive amount of hyperspectral image data seriously limits the processing speed. Real-time image processing based on hardware platform, such as digital signal processor (DSP), is one of recent developments in hyperspectral target detection. In hyperspectral target detection algorithms, correlation matrix or covariance matrix calculation is always used to whiten data, which is a very time-consuming process. In this paper, a strategy named spatial-spectral information extraction (SSIE) is presented to accelerate the speed of hyperspectral image processing. The strategy is composed of bands selection and sample covariance matrix estimation. Bands selection fully utilizes the high-spectral correlation in spectral image, while sample covariance matrix estimation fully utilizes the high-spatial correlation in remote sensing image. Meanwhile, this strategy is implemented on the hardware platform of DSP. The hardware implementation of constrained energy minimization (CEM) algorithm is composed of hardware architecture and software architecture. The hardware architecture contains chips and peripheral interfaces, and software architecture establishes a data transferring model to accomplish the communication between DSP and PC. In experiments, the performance on software of ENVI with that on hardware of DSP is compared. Results show that the processing speed and recognition result on DSP are better than those on ENVI. Detection results demonstrate that the strategy implemented by DSP is sufficient to enable near real-time supervised target detection.

8390-94, Poster Session

A target segmentation algorithm based on multivariate statistics and RX anomaly detection

Q. Guo, B. Zhang, L. Gao, X. Sun, W. Zhang, Ctr. for Earth Observation and Digital Earth (China)

Anomaly detection of hyperspectral image is very active in the field of remote sensing image processing. RXD developed by Reed and Yu is a constant false alarm rate (CFAR) anomaly detection algorithm founded on multivariate statistical analysis theory, as the same form with Mahalanobis distance. RX detector could enable researchers to detect targets whose signatures are spectrally distinct from their surroundings, so it is practicable in real scenes, and then becomes a focus in the field of target detection.

RX detector has two common forms, Global-RX and Local-RX. They have different samples to estimate mean vector and covariance matrix. PCA is a common preprocessing step for dimension reduction. Interestingly, because it can also remove noises, performance could be improved by using principle components instead of all data. In addition, researchers often assume that RX result values submit chi square distribution, but setting threshold value based on chi square distribution leads unacceptable high false alarm rate, so how to get threshold value has been a difficult problem, the paper proposes a method based on multivariate statistical probability theory which can segment targets from image automatically. Instead of a constant threshold value, this segmentation target approach use an initial threshold calculated by RX result value histogram to separate backgrounds and targets samples, then calculate every pixel's posterior probabilities of background or target by assuming they all submit multi-dimensional normal distribution. Generally, the higher probability is considerable. The proposed method has been tested using AVIRIS data and the experimental results reveal that segmentation target approach has a better capability than traditional manual thresholding on higher detection probability and lower false alarm rate.

8390-95, Poster Session

Vehicle detection in WorldView-2 satellite imagery based on Gaussian modeling and contextual learning

B. Shen, C. Chen, Univ. of Massachusetts Dartmouth (United States); G. Marchisio, DigitalGlobe, Inc. (United States)

Since the launch of the geophysical remote sensing satellite WorldView-2 in October 2009, it has collected a large amount of data, which has many important applications in traffic and road network management, city planning and growth, environmental monitoring, resource management, mineral exploration, land cover identification and classification, and agriculture. With the increased spatial resolution of 0.5m and extended 8-band spectral coverage and fidelity, and a large scanning area of 550,000 square km per day, its multispectral imagery has the capability to extract features and signatures from land, water, trees, vegetation, and many man-made objects and materials. It has a great value in helping to analyze human activities and understand the earth and the impacts of natural processes. In this paper, we aim to study the detection of vehicles from WorldView-2 satellite imagery. For this purpose, accurate modeling of vehicle features and signatures and efficient learning of vehicle hypotheses are critical. However, this is not trivial as most of vehicle details and characteristic features are lost during the image capturing process, and different vehicle types, colors, sizes, heights and orientations cause a lot of variations during projection, although vehicles may be geometrically represented as rectangular shapes in limited scales. Additionally, wide area coverage may include very similar non-vehicle features due to building roofs and parts, trees, walls, shadows, and other objects. The high detection results and evaluations demonstrate the effectiveness of the vehicle detection algorithm. We present a joint Gaussian and maximum likelihood based modeling and machine learning approach using SVM and neural network algorithms to describe the local appearance densities and classify vehicles from non-vehicle buildings, objects, and backgrounds. Vehicle hypotheses are fitted by elliptical Gaussians and the bottom-up features are grouped by Gabor orientation filtering based on multi-scale analysis and distance transform. Global contextual information such as road networks and vehicle distributions can be used to enhance the recognition. In consideration of the problem complexity the practical vehicle detection task faces due to dense and overlapping vehicle distributions, partial occlusion and clutters by building, shadows, and trees, we employ a spectral clustering strategy jointly combined with bootstrapped learning to estimate the parameters of centroid, orientation, and extents for local densities. We demonstrate a high detection rate 94.8%, with a missing rate 5.2% and a false alarm rate 5.3% on the WorldView-2 satellite imagery. Experimental results show that our method is quite effective to model and detect vehicles.

8390-96, Poster Session

Data-driven ultrasonic signal analysis using empirical mode decomposition for nondestructive material evaluation

B. Shen, C. Chen, Univ. of Massachusetts Dartmouth (United States)

Phased array ultrasonic sensing is a well-known non-destructive evaluation approach and a lot of research efforts have been reported. In this paper, we study flaw identification and localization in coarse-grained steel components. To improve the detection effectiveness and performance, advanced ultrasonic signal processing plays a key role. We propose a non-parametric data-driven approach based on ensemble empirical mode decomposition (EEMD), an effective and powerful method to analyze the nonlinear and non-stationary characteristics of the ultrasonic signals. In the EEMD approach, white noise is added and it will assist the sifting iterations to converge to the truly intrinsic mode functions (IMF) and cancel out the added noise as long as the iterations are sufficiently large. It is shown that the ultrasonic wave-front harmonics can be effectively represented by multi-mode IMFs, which have the well-defined local time scales and instantaneous frequencies. And the sifting iterations adapt to the varying physical process meaningfully. Numerical experiments are conducted and the presented results validate the effectiveness and advantages of our proposed approach over conventional methods.

8390-97, Poster Session

Developing high-resolution clutter for wireless network propagation using WorldView-2 imagery

B. B. Gwata, ComputaMaps (South Africa)

The telecommunication industry has been driven to provide better network coverage while reducing costs due to the increasing competitive nature of the market. In order to optimize network coverage, the best locations have to be identified for Base Stations and other Transmitters. High resolution clutter classes are significant for the accurate propagation and optimization of wireless networks. Signal loss prediction models can be rendered according to the characteristics of the land cover and terrain. Due to the high demand for 3D data for networks such as 3G+ and 4G, there is an increased demand for accurate, high resolution clutter data.

WorldView-2 Imagery will provide the platform to develop high resolution clutter due to its spectral diversity and high resolution. The increased spectral bands have the potential of separating classes such as grassland and rangeland which usually have similar spectral characteristics. Over the past, one of the major challenges in the extraction of vegetation within urban environments has been spectral mixing of urban fabric and vegetation due to coarser imagery. The high resolution of WorldView-2 will allow more accurate extraction of the different vegetation classes within the urban environment.

The main goal of this study is to investigate each of the eight spectral bands of the new Worldview-2 imagery for semi-automated clutter production. A number of ratios and indexes from the eight spectral bands will also be introduced and analyzed. The optimal bands and band ratios for the extraction of each clutter class will then be identified and presented.

8390-98, Poster Session

New feature for evaluation of supervised classification

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As acquisition technology progresses, remote sensing data contains an ever increasing amount of information: optical and radar images, low, high and very high-resolution, high/multi -temporal -spectral images, and physical or ancillary data (databases, Digital Elevation Model (D.E.M), Geographical Information System (G.I.S.)). Future projects in remote sensing will give high repeatability of acquisition like Venµs (CNES) which may provide data every 2 days with a resolution of 5.3 meters on 12 bands (420nm-900nm) and Sentinel-2 (ESA) 13 bands, 10-60m resolution and 5 days. With such data, supervised classification gives excellent results in term of accuracy indices (Overall Accuracy, Kappa coefficient, etc) but significative confusion still existing between some classes. In this paper, we present an overview of existing indices with their advantages and disadvantagess and propose a new index to evaluate supervised classification using all the information available from the confusion matrix. In addition to accuracy, a new feature is introduced: fidelity. For example, a class could have an high accuracy (low omission error) but could be over-represented in other classes (high commission error). The new index reflect accuracy and correct representation of classes (fidelity) using commission and omission errors. Environment applications are in land cover and land use and the goal is to have the best classification for all classes, whether the biggest (corn, trees) or the lightest (rivers, hedges). The tests are performed on Formosat-2 images (every 2 days, 8 meters resolution on 4 bands) in the area of Toulouse (France). Tests used to validate the new index by demonstrating benefits of its use through various thematics studies.

8390-40, Session 9

Data model, LUT-based change and anomaly detection for real-time multispectral image characterization

H. M. Jaenisch, Licht Strahl Engineering, Inc. (United States) and Johns Hopkins Univ. (United States); J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We present a method for partitioning a multispectral image into fixed size Look-up-tables LUTs that are dynamically updated for presence or absence of simple distribution characterizing features of the sub-frames they represent. If the features has been previously observed it is recognized and no update occurs, if not the table is updated and a suitable anomaly reported. Our method enbles dynamic change detection to occur at multiple wavelengths independently be creating suitable LUTs for each wavelength band. Details of our approach are presented.

8390-41, Session 9

Extended development of model-based change detection

J. Meola, Air Force Research Lab. (United States)

Hyperspectral change detection provides an avenue for detecting subtle targets in complex backgrounds. Complicating the problem of change detection is the presence of shadow, illumination, and atmospheric differences, as well as misregistration and parallax error, which often produce the appearance of change. Recent development of a model-based approach to hyperspectral change detection has demonstrated potential improvement for mitigating false alarms due specifically to shadow differences using calibrated data. Further development and application of the model-based approach is provided here. The method is extended for use on both uncalibrated and relatively calibrated hyperspectral data and is applied to airborne hyperspectral imagery collected using the HYDICE visible to short-wave infrared sensor and uncalibrated tower imagery collected by the Air Force Research Laboratory.

8390-42, Session 9

Developing a portable GPU library for hyperspectral image processing

G. J. Perez-Irizarry, F. De La Cruz-Sanchez, N. G. Santiago-Santiago, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Advances in graphical processing units (GPUs) have made possible their use for general purpose scientific and engineering computing. GPUs have evolved over the years and now have massive parallel computing power. It is common for GPUs to feature hundreds of cores and GFlops of computing power. Also platforms such as OpenCL and CUDA have been developed to facilitate the use of GPUs for general purpose computing. An area where this parallel processing power can be used is the processing of hyper-spectral images and detection algorithms.

A high performance, documented, and cross-platform GPU library for hyper-spectral image processing is being developed at the University of Puerto Rico Mayaguez (UPRM). This library takes advantage of GPUs and the CUDA framework by NVIDIA to drastically improve execution times of some hyper-spectral image processing algorithms. A key challenge in the development of the library is portability. Being able to serve this library for multiple platforms entails many complications. These complications arise due to the different back-ends supported, since these back-ends have many dependencies and are highly configurable. To make individual routines optimally run on different platforms require a lot of testing and tweaks because subtle differences in platforms can bring about issues with library linking, installation and execution. Examples using RX and AMSD detector are presented.

8390-43, Session 9

Development of an efficient, automated hyperspectral processing system using embedded computing

M. S. Brown, E. Glaser, J. Curreri, S. Grassinger, M. Z. Salvador, Logos Technologies, Inc. (United States)

Automated hyperspectral processing enables rapid detection and identification of important military targets in near real time. This capability provides up-to-date intelligence, allowing rapid responses to situations as they unfold. Typically, automated HSI processing is deployed on standard CPU-based hardware, with some efforts to move to GPU-based processing. However, as the aerial platforms hosting the hyperspectral system migrate from large manned aircraft to smaller UAVs, alternative architectures will be required. Utilizing an embedded system can reduce the size, weight, and power (SWaP) requirements of the hyperspectral processing system. This will allow the next generation of hyperspectral systems to be deployed on a much wider range of unmanned vehicles.

In this paper, we present results on the development of an automated hyperspectral processing system engineered for various embedded systems (GPU, DSP, FPGA). The SWaP goals for the embedded processor are less than 0.2 ft3, 15 lbs, and 200 watts, while operating at greater than 600 GFLOP. Operational throughput requirements for automated hyperspectral processing will be discussed, and the computational speed, algorithm performance, and SWaP of our embedded systems will be compared with traditional CPU-based systems.

8390-44, Session 9

Integrating spectral preprocessing, spatial subband decomposition, and linear prediction to accomplish lossy ultraspectral image compression

R. Herrero, V. K. Ingle, Northeastern Univ. (United States)

We propose a new architecture to accomplish lossy ultraspectral data compression where we particularly focus on AIRS (Atmospheric Infrared Sounder) images. In general AIRS images are good candidates for compression as they include more than two thousand spectral bands that account for over 40MB of data per single data cube. In our proposed compression technique the input image is first preprocessed by means of spatial subband decomposition followed by a spectral band ordering stage which is applied in order to increase the correlation between contiguous spectral bands. The resulting image is segmented on a spectral band basis in such a way that spectral bands are scanned to generate a speech-like signal that exhibits a higher spectral interband than intraband correlation and therefore can be modeled as an AR (autoregressive) process. As final step the data is processed through a compression stage involving short and long term forward linear prediction that produces an error signal that is encoded using a CELP (Code Excited Linear Prediction) scheme. The forward linear prediction filter order and the resolution of the CELP codebooks are adjusted depending on the spatial subband that originates the signal being predicted.
By manipulating several parameters of both the preprocessing and compression stages different rate-distortion curves are obtained and highly efficient compression is achieved.

8390-45, Session 9

Hyperspectral imaging using compressed sensing

G. Ramirez, V. B. Manian, Univ. de Puerto Rico Mayagüez (United States)

Compressed sensing (CS) has attracted a lot of attention in recent years as a promising signal processing technique that exploits a signal's sparsity to reduce its size. It allows for simple compression that does not require a lot of additional computational power, and would allow physical implementation at the sensor using spatial light multiplexers as Texas Instrument's (TI) digital micro-mirror device (DMD). The DMD can be used as a random measurement matrix, reflecting the image off the DMD is the equivalent of an inner product between the images individual pixels and the measurement matrix. CS however is asymmetrical, meaning that the signals recovery or reconstruction from the measurements does require a higher level of computation. This makes the prospect of working with the compressed version of the signal in implementations such as detection or classification much more efficient. If an initial analysis shows nothing of interest, the signal need not be reconstructed. Many hyper-spectral image applications are precisely focused on these areas, and would greatly benefit from a compression technique like CS that could help minimize the light sensor down to a single pixel, lowering costs associated with the cameras while reducing the large amounts of data generated by all the bands. The present paper will show an implementation of CS using a single pixel hyper-spectral sensor, and compare the reconstructed images to those obtained through the use of a regular sensor. It will also explore the possibility of classification or detection on the compressed signal.

8390-99, Session 9

Computational modeling of skin reflectance spectra for biological parameter estimation through machine learning

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A hyperspectral imaging based computational skin reflectance model, coupled with machine learning algorithms is used to predict the constitutive biological parameters that make up the layers of the skin. In our preliminary experiments, performance validation using VIS Hyperspectral data shows very encouraging results.

8390-47, Session 10

Hyperspectral measurements of natural signatures: pedestrians

J. Herweg, J. P. Kerekes, Rochester Institute of Technology (United States); M. T. Eismann, Air Force Research Lab. (United States)

In the hyperspectral imaging community, there is a need for relevant and valid data for testing scientific principles. Several sets of data exist which support satellite and airborne HSI research applications. However, there is a need for data sets to support research in support of detecting and classifying smaller targets such as pedestrians. While many studies capture data on pedestrians, the data sets are often only related to the specific study being conducted. As a result, these types of data sets do not contain the necessary documentation or ground truth needed to apply the data in other contexts. This paper reports on a fully ground truthed HSI data set which was captured in June 2011 over an urban scene with pedestrians present. The imagery was collected using a modified airborne imager suited for ground level imaging in the 450 - 2500 nm wavelength region. The data captured are described along with the ground truth information and documentation which are part of the data package. Preliminary results from an initial study on material spectral separability using the data are included to demonstrate the utility of this particular data set.

8390-48, Session 10

Linking goniometer measurements to hyperspectral and multisensor imagery for retrieval of beach properties and coastal characterization

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In June 2011, a multi-sensor airborne remote sensing campaign was flown at the Virginia Coast Reserve LTER with coordinated ground and water calibration and validation measurements. Remote sensing imagery acquired during the ten day exercise included hyperspectral imagery (CASI), topographic LiDAR, and thermal infra-red imagery, all simultaneously from the same aircraft. Airborne synthetic aperture radar (SAR) data acquisition for a smaller subset of sites occurred in September 2011 (VCR'11). Focus areas for VCR'11 were properties of beaches and tidal flats and barrier island vegetation and, in the water column, shallow water bathymetry. On land, cal/val emphasized tidal flat and beach grain size distributions, density, moisture content, and other geotechnical properties such as shear and bearing strength (dynamic deflection modulus) which were related to hyperspectral BRDF measurements taken with the new NRL Goniometer for Outdoor Portable Hyperspectral Earth Reflectance (GOPHER), building on earlier work (2007) related to beach properties (Bachmann, Nichols, et al, 2010) and shallow water bathymetry (Bachmann, Montes, et al, 2010). A priority for VCR'11 was to collect and model relationships between hyperspectral imagery, acquired from the aircraft at a variety of different phase angles, and geotechnical properties of beaches and tidal flats as well as biophysical properties of vegetation. The shape of the hyperspectral reflectance about the retro-reflectance direction is closely related to important geophysical parameters such as grain size and density (for granular surfaces) (Hapke, 1993; 2002; 2008; 2009) and biophysical parameters such as biomass and leaf area index (LAI) for vegetation (Hapke, 1993; Asrar, 1989).

8390-49, Session 10

High-spatial and high-spectral thermal infrared remote sensing at the Jet Propulsion Laboratory

S. J. Hook, Jet Propulsion Lab. (United States)

The NASA/Jet Propulsion Laboratory is undertaking a variety of activities related to understanding the spectral properties of materials at high spatial and spectral resolutions in the mid through thermal infrared (3-13 micrometers). These include the development of the ASTER Spectral Library, Quantum Well Earth Science Testbed (QWEST), Hyperspectral Thermal Emission Spectrometer (HyTES), Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR) and Hyperspectral Infrared Imager (HyspIRI). Each of these different activities will be summarized together with examples of the types of data the different instruments will produce and how such data may be used to address a variety of science and applications. The ASTER spectral library is a collection of over 2000 laboratory spectra of a wide variety of materials measured between 0.4 and 14 micrometers. The library was generated from directional hemispherical measurements made by multiple instruments and includes contributions from several organizations. The library has now been ordered over 5000 times and is widely used as a standard reference dataset. QWEST is a QWIP based imaging spectrometer which was designed to utilize several new JPL technologies and as a breadboard for HyTES which is an airborne hyperspectral imager. HyTES has 256 spectral channels between 7.5 and 12 micrometers with a swath width of 512 pixels and spatial resolutions of a few meters. HyTES is currently being assembled with first flights planned for late 2012. PHyTIR is a laboratory prototype for the thermal infrared instrument on spaceborne HyspIRI mission. HyspIRI is one of the Tier 2 Decadal Survey Missions.

8390-50, Session 10

Spectral-feature-based analysis of reflectance and emission spectral libraries and imaging spectrometer data

F. A. Kruse, Naval Postgraduate School (United States)

This research demonstrates the application of spectral-feature-based analysis to identifying and mapping Earth-surface characteristics using spectral libraries and imaging spectrometer data. Feature extraction utilizing a continuum-removal and local minimum detection approach was tested for analysis of both reflectance and emissivity spectral libraries by extracting and characterizing spectral features of rocks, soils, minerals, and man-made materials. Library-derived information was then used to illustrate both reflectance and emissivity feature-based spectral mapping using imaging spectrometer data (AVIRIS, ProSpecTIR, and SEBASS). An additional spectral library of emission spectra from selected lights was used to develop a database of key spectral features that allowed mapping and characterization of night lights from ProSpecTIR imaging spectrometer data. Results from these case histories demonstrate that the spectral-feature-based approach can be used with either reflectance or emission spectra and applied to a wide variety of imaging spectrometer data types for extraction of key surface composition information.

8390-51, Session 11

Automated tracking of flooding using WorldView-2 imagery

J. Doubleday, S. Chien, Jet Propulsion Lab. (United States)

We investigate the use of Worldview-2 Multipspectral (8-band), high spatial resolution (2m) data for active flood mapping within an automated sensorweb concept.

We examined the use of two water extent classifiers that use ratios of the raw spectral signal at two wavelengths. These classifiers had originally been developed for the Hyperion instrument flying onboard the Earth Observing One spacecraft [Ip et al. 2006] and leverage spectral information at the 0.55µm/0.86µm, 0.99µm/0.86µm wavelengths. The 0.55µm/0.86µm spectral ratio has also been used for surface water extent classification in Advanced Land Imager (ALI) data from the EO-1 spacecraft.

In the second part of our effort we used Support Vector Machine Learning Methods [Schölkopf & Smola 2002]. to automatically learn a surface water extent classifier to discriminate between flooded areas, land, and clouds. In this effort we used the JPL developed PixelLearn system. We specified cloud, land water, shadowed land, and shadowed water as distinct classes and then generated an SVM classifier using a Gaussian kernel.

8390-52, Session 11

Automatic identification of volcanic ash plumes in multilook multispectral WorldView-2 imagery

D. R. Thompson, S. Chien, Jet Propulsion Lab. (United States)

We investigate automatic extraction of plume area, height, and approximate velocity, from a sequence of WV-2 imagery. Specifically we analyze a sequence of several images from the Eyjafjallajokull eruption in Iceland in Spring 2010 using texture-based classification methods.

We use the integral image transform to produce pixel-level texture features. A decision tree using integer arithmetic computes pixel classifications far faster than texture analysis techniques requiring convolutions of steerable filter banks. The multispectral, multi-look, high spatial resolution WV-2 data offers a unique opportunity. Automatic extraction of this information can significantly improve the science of volcanology by automatically providing objective science measurements from larger image archives.

8390-53, Session 11

Using multi-angle WorldView-2 imagery to determine ocean depth near the island of Oahu, Hawaii

K. R. Lee, R. C. Olsen, F. A. Kruse, Naval Postgraduate School (United States)

Multispectral imaging (MSI) data acquired at different view angles provide an analyst with a unique view into shallow water. Observations from DigitalGlobe's WorldView-2 (WV-2) sensor, acquired in 39 images in one orbital pass on 30 July 2011, will be analyzed for bathymetry data taken along the windward side of the Oahu coastline. Satellite azimuth and elevation range from 18.8 to 185.8 degrees and 24.9 to 77.8 degrees (respectively). WV-2's eight multispectral bands provide depth information (especially using the Blue, Green, and Yellow bands), as well as information about bottom type and surface glint (using the Red and NIR bands). Bathymetric analysis from the optical data are compared to LiDAR-derived bathymetry. This work shows the impact of varying view angle on inferred bathymetry and discusses the differences between angle acquisitions.

8390-54, Session 11

Shallow water benthic mapping with WV02

G. Miecznik, DigitalGlobe, Inc. (United States)

The 2009-launched WorldView02 satellite by DigitalGlobe, Inc., with 8 spectral bands across approximately 400-1000nm part of the solar spectrum, is capable of mapping shallow water benthic environment at 2x2m spatial resolution. At the same time, owing to the satellite high maneuver agility and frequent revisit time, WV02 provides opportunity to monitor benthic changes at a high temporal resolution, as well as provide nearly simultaneous measurements of the target area from multiple views on the same orbit. Recent algorithm work, based on radiative transfer modeling and a-priori information obtained from spectral libraries of representative bottom types, shows that WV02 can be used under nominal weather conditions, to map shallow water depth (approximately down to 30m) and discriminate between topical bottom types to a precision comparable with LIDAR and hyperspectral instruments. Results of retrieved water depth, bottom type and water properties are compared with detailed in-situ measurements across numerous sites in Bahamas, Queensland, and the Great Barrier Reef.

8390-55, Session 11

Refinement of a method for identifying probable archaeological sites from remotely sensed data

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To facilitate locating archaeological sites before they are compromised or destroyed, we are developing approaches for generating maps of probable archaeological sites, through detecting subtle anomalies in vegetative cover, soil chemistry, and soil moisture by analyzing remotely sensed data from multiple sources. We previously reported some success in this effort with a statistical analysis of slope, radar, and Ikonos data (including tasseled cap and NDVI transforms) with Student's t-test. We report here on new developments in our work, performing a combined analysis of an Archaeological Predictive Model (APM) and 8-band multispectral Worldview-2 data. The Worldview-2 analysis begins by computing medians and median absolute deviations for the pixels in various annuli around each site of interest on the 28 band difference ratios. We then use principle components analysis followed by linear discriminant analysis to train a classifier which assigns a posterior probability that a location is an archaeological site. We tested the procedure using leave-one-out cross validation with a second leave-one-out step to choose parameters on a 9,859x23,000 subset of the WorldView-2 data over the western portion of Ft. Irwin, CA, USA. We used 100 known non-sites and trained one classifier for lithic sites (n=33) and one classifier for habitation sites (n=16). We then analyzed convex combinations of scores from the APM and our scores. We found that that the combined scores had a higher area under the ROC curve then either individual method, indicating that including WorldView-2 data in or analysis improved the predictive power of the provided APM.

8390-56, Session 12

Using physics-based macroscopic and microscopic mixture models for hyperspectral pixel unmixing

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A method of incorporating macroscopic and microscopic reflectance models into hyperspectral pixel unmixing is presented and discussed. A vast majority of hyperspectral unmixing methods rely on the linear mixture model to describe pixel spectra resulting from mixtures of endmembers. Methods exist to unmix hyperspectral pixels using nonlinear models, but rely on severely limiting assumptions or estimations of the nonlinearity. This paper will present a hyperspectral pixel unmixing method that utilizes the bidirectional reflectance distribution function to model microscopic mixtures. Using this model, along with the linear mixture model to incorporate macroscopic mixtures, this method is able to accurately unmix hyperspectral images composed of both macroscopic and microscopic mixtures. The mixtures are estimated directly from the hyperspectral data without the need for a priori knowledge of the mixture types. Results are presented using synthetic datasets, of macroscopic and microscopic mixtures, to demonstrate the increased accuracy in unmixing using this new physics-based method over linear methods. In addition, results are presented using a well-known laboratory dataset. Using these results, and other published results from this dataset, increased accuracy in unmixing over other nonlinear methods is shown.

8390-57, Session 12

Priors in sparse recursive decompositions of hyperspectral imagery

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Nonnegative matrix factorization (NMF) and its variants are powerful techniques for the analysis of hyperspectral images (HSI). In fact, they provide a suitable mathematical framework to unmix HSI using the so-called linear mixture model: the spectral signature of each pixel results from the additive linear combination of the spectral signatures of the constitutive materials present in the scene being imaged Nonnegative matrix underapproximation (NMU) is a recent closely related model that uses additional underapproximation constraints enabling the extraction of features in a recursive way (such as PCA) while preserving nonnegativity (such as NMF). NMU has been theoretically and experimentally shown to robustly extract constitutive materials in HSI. In this paper, we significantly improve the sparse representation NMU model by adding the following two priors: spatial information (i.e., neighbor pixels are likely to contain the same materials) and piecewise smoothness of the spectral signatures. Both priors are taken into account using an ell_1-norm penalty term added in the objective function. Compared to the more standard ell_2-norm penalty, ell_1-norm has the disadvantage of being non-differentiable. However, it is much less sensitive to sharp changes in the abundance maps (e.g., at the boundary of two materials) and in the spectral signatures, leading to improved unmixing

performance. The corresponding optimization subproblems are solved using recent convex optimization techniques for minimizing non-smooth objective functions. Finally, we illustrate the improvement of this new technique on both synthetic and real-world HSI datasets.

8390-58, Session 12

Incorporating local information in unsupervised hyperspectral unmixing

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In hyperspectral imaging, the radiation represented by a single pixel in the remotely sensed image rarely comes from the interaction with a single homogeneous material. However, the high spectral resolution of imaging spectrometers enables the detection, identification, and classification of subpixel objects from their contribution to the measured spectral signal. Unmixing is a hyperspectral image processing approach where the measured spectral signature is decomposed into a collection of constituent spectra, or endmembers, and a set of corresponding fractions or abundances which correspond to the fractional area occupied by the particular endmember in that pixel. The use of a single spectra to represent an endmember class does not take into account the variability of spectral signatures caused by natural factors. Simple spectral mixture analysis can, by itself, provide suitable accuracies in some relatively homogeneous environments, but because of the spectral complexity of many landscapes, the use of fixed endmember spectra may results in inaccurate unmixing analysis for complex regions over large landscapes. This paper addresses the question of how to perform unsupervised unmixing where local information is used to extract local endmember information and merged at a global level to extract endmembers classes for developing an accurate description of the scene under study. Preliminary results using AVIRIS and AISA data are presented. Results show that this approach better captures local structures that are not possible with global unmixing approach.

8390-59, Session 12

Endmember extraction for hyperspectral image unmixing using multiscale segmentation

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Automated unmixing consists to find the number of endmembers, the spectral signatures and the abundance map from a hyperspectral image. Most unmixing techniques are pixel-to-pixel procedures that do not take advantage of spatial information provided by hyperspectral sensor. Some spatial-spectral algorithms have been proposed for endmember extraction using common techniques of image processing such as morphologic operations, spatial kernels and segmentation. This paper explores a new approach for unmixing analysis of hyperspectral imagery using a multiscale segmentation method for the joint estimation of the number of endmember and their spectral signatures. Assuming that the pixels in a hyperspectral imagery can be either a pure constituent or a mixed pixel, the number of endmember can be determined by the number of spectrally distinct regions in the image. A multiscale segmentation algorithm is used to extract representative spectral signatures from spectrally uniform regions. These representatives are used to determine the number of endmember and the endmember class.. Experimental results using AISA and AVIRIS imagery are presented.

8390-60, Session 13

A spectral image clustering algorithm based on ant colony optimization

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Ant Colony Optimization (ACO) is a computational method used to optimize over large multidimensional solution spaces. The ACO algorithm uses virtual ants to create candidate solutions that are represented by paths on a mathematical graph. Ants apply “pheromones” to the paths they create in an amount relative to the quality of the solution represented by the path. The solution can also be constrained through application of “rules” governing how the ants create the paths. In this way future ants are drawn towards better solutions on the graph. We develop an algorithm using ACO that takes a spectral image as input and outputs a cluster map denoting a cluster label for each pixel. We apply the algorithm to multi- and hyperspectral imagery in an attempt to divide the pixels into different clusters based on their representation by a low dimensional manifold estimated by the best fit “ant path” through the data cloud. We construct the graph by creating a node for each pixel in the image. We connect nodes together on the graph based on the similarity of the pixels they represent measured by the Euclidean distance between them in the spectral space. We compare the results of this algorithm to other commonly used clustering algorithms.

8390-61, Session 13

Hyperspectral image segmentation using spatial-spectral graphs

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Spectral graph theory has proven to be a useful tool in the analysis of high-dimensional data sets. Recall that, mathematically, a graph is a collection of objects (nodes) and connections between them (edges); a weighted graph additionally assigns numerical values (weights) to the edges. Graphs are represented by their adjacency whose elements are the weights between the nodes. Spectral graph theory uses the eigendecomposition of the adjacency matrix (or, more generally, the Laplacian of the graph) to derive information about the underlying graph.

In this paper, we develop a spectral method based on the ‘normalized cuts’ algorithm to segment hyperspectral image data (HSI). In particular, we model an image as a weighted graph whose nodes are the image pixels, and edges defined as connecting spatial neighbors; the edge weights are given by a weighted combination of the spatial and spectral distances between nodes. We then use the Laplacian of the graph to recursively segment the image. The advantages of our approach are that, first, the graph structure naturally incorporates both the spatial and spectral information present in HSI; also, by using only spatial neighbors, the adjacency matrix is highly sparse; as a result, it is possible to apply our technique to much larger images than previous techniques. In the paper, we present the details of our algorithm, and include experimental results from a variety of hyperspectral images.

8390-62, Session 13

Kernel-based joint spectral and spatial exploitation using a Hilbert space embedding for hyperspectral classification

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Support Vector Machine (SVM) has been widely used as an efficient classification technique for hyperspectral classification problems due to its capability of exploiting nonlinear structure of data by discriminant analysis without estimating probability distributions. A majority of SVM-based techniques developed to date, exploit only spectral information

ignoring spatial context that also conveys valuable information about targets of interest. Joint exploitation of both spectral and spatial information is highly desirable to improve detection performance of targets. However, in hyperspectral literature, only a few attempts have been made to jointly exploit both spectral and spatial information of hyperspectral images. These methods are heuristic and combine the Reproducing Kernel Hilbert Spaces (RKHS) using a weighted average of spectral and spatial (mean or standard deviation) kernel matrices.

In this paper, in order to optimally exploit the spectral and spatial information of the hyperspectral image, we propose to use a novel idea of embedding a distribution of input hyperspectral data into the RKHS. In the proposed work, a Hilbert Space Embedding called mean map is utilized to map a group of neighboring pixels of a hyperspectral image into the RKHS and then, calculate the empirical mean of the mapped points in the RKHS. SVM based classification performed on the mean mapped points can fully exploit the spectral information as well as ensure spatial continuity among neighboring pixels. The proposed technique showed significant improvement over the existing composite kernels on the Indian Pines dataset.

8390-63, Session 13

Automatically enumerating data clusters using pixel codensity

R. A. Mercovich, Rochester Institute of Technology (United States)

A common and difficult task in spectral image analysis is automatic clustering. Typical automatic clustering methods struggle to determine the correct number of clusters to properly characterize the data. Although some techniques estimate the number of clusters as they group pixels, the appropriate number of clusters is often arrived at based upon preset parameters. To estimate the number of clusters in a spectral image data cloud explicitly from the data structure, the pairwise relationships between pixels can be exploited. Utilizing a distance function, the image pixel data points can be compared to all other pixels in the n-dimensional spectral space. The average kth-codensity, the average distance from each pixel to its kth nearest neighbor, can characterize the neighborhoods in a data cloud. A sharp increase in average distance from the kth neighbor to neighbor k+1 indicates a gap between clusters. By plotting the average neighbor distance to every neighbor in the image, a monotonically increasing function will emerge that characterizes the clusters in the data. The number of large steps in the average neighbor distance function is the number of well-grouped clusters in the data. Through some simple signal processing on the approximate discrete derivative of the average neighbor distance plot, the number of clusters in a spectral image data cloud can be easily counted by automatically identifying local maxima in a time-series. This process can accurately identify the number of clusters in a wide variety of image data with no user input, and provides a useful tool for clustering or change detection.

8390-64, Session 13

Crop classification in Afghanistan using high-resolution, multispectral imagery

R. R. Vatsavai, B. Bhaduri, Oak Ridge National Lab. (United States)

In many practical situations it is impossible to collect labeled samples for all available classes in a domain. Especially in supervised classification of remotely sensed images it is impossible to collect ground truth information over large geographic regions for all thematic classes. This leads two problems: (1) small training samples, (2) aggregate classes. We developed a novel semi-supervised classification framework to address these two challenging practical problems. We used the expectation maximization (EM) technique for estimating mixture model parameters with pooled labeled and unlabeled training samples. This technique solves the first problem, that is, small training samples in supervised classification. We further extended this basic framework to address aggregate class ground-truth problem. Instead of unimodal Gaussian class distribution, we assume that the user given training samples are drawn from Gaussian Mixture Model (GMM). This model parameters are estimated using EM technique. Unlike regular semi-supervised learning, in this aggregate class setup we also need to estimate the number of components in the model. This novel framework is applied on the classification of crops in Afghanistan with limited ground-truth data. Initial experimental results on WV-2 multispectral image data showed a 10-15% improvement in overall classification accuracy.

8390-65, Session 14

Feature extraction, anomaly, and change detection on WorldView-2 imagery by hierarchical image segmentation: a study

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We study spatio-spectral feature extraction and image-adaptive anomaly and change detection on 8-band Worldview-2 imagery using a hierarchical polygonal image segmentation scheme. Features are represented as polygons with spectral and structural attributes, along with neighborhood structure and containment hierarchy for contextual feature identification. Further, the hierarchical segmentation provides multiple, coarse-scale, sub-backgrounds representing relatively uniform regions, which localize and simplify the spectral distribution of an image. This paves the way for facilitating anomaly and change detection when restricted to the contexts of these backgrounds. For example, forestry, urban areas, and agricultural land have very different spatio-spectral characteristics and their joint contribution to the image statistics can result in a complex distribution against which detecting anomalies could in general be a challenging problem. Our segmentation scheme provides sub-regions in the later stages of the hierarchy that correspond to homogeneous areas of an image while at the same time allowing inclusion of distinctive small features embedded in these regions. The exclusion of other image areas by focusing on these sub-backgrounds helps discover these outliers more easily with simpler methods of discrimination.

By selecting appropriate bands in WV-2 imagery, the above approach can be used to achieve fine spatio-spectral control in searching and characterizing features, anomalies, and changes of interest. The anomalies and changes are also polygons which have their spectral and structural attributes associated with them, allowing further characterization in the larger context of the image. The segmentation and feature detections can be used as multiple layers in a GIS for annotating imagery.

8390-66, Session 14

Multispectral land-cover model portability analysis using multi-angle very high-spatial-resolution data

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Very-high spatial resolution (VHR) imagery provides the necessary detail to distinguish typical urban features. It is possible to create classification maps of basic land-cover types from this type of multispectral data using standard machine learning techniques. Additional derived information, based on techniques such as texture and morphology, has been shown to improve the ability to classify land-cover types.

However, the ability to train a classifier and accurately apply (port) the classifier from one image to another is an outstanding question. Derived information does not always improve the portability of a trained model, especially in the case of urban classes with limited spatial variability. Therefore, techniques have increasingly relied on data space normalization, such as atmospheric correction, machine learning, and band normalization.

In this presentation, we present a method to analyze the impact of data space normalization on spectral model portability using multi-angle VHR imagery. In-track multi-angle data, such as that provided by highly agile satellites like DigitalGlobe WorldView-1 and WorldView-2, provide images of a single scene, from different observation angles, during a very short period of time. This creates a sequence of images with a relatively static atmospheric and illumination conditions. With this data, the only changes in the scene are due to observation angle and surface reflectance properties. Using this information, we present an analysis of both the impact of surface anisotropy and data space normalization on spectral classification accuracy and model portability.

8390-67, Session 14

An automated approach for constructing road network graph from multispectral images

W. Sun, D. Messinger, Rochester Institute of Technology (United States)

We present an approach for automatically constructing a road network graph from multispectral WorldView II images in suburban and urban areas. In this graph, the road parts are represented by edges and their connectivity by vertices. This approach consists of an image processing chain utilizing both high-resolution spatial features as well as multiple band spectral signatures from satellite images. Based on an edge-preserving filtered image, a two-pass spatial-spectral flood fill technique is adopted to extract an asphalt class map. This technique requires only one pixel as the initial training set and collects spatially contiguous and spectrally similar pixels to the initial point as a second level training set for a higher accuracy asphalt classification. Based on the class map, a road network graph is built after a series of morphological processing and curve segmentation. The graph projects a logical representation of the road network in an urban image. Rules can be made to filter salient road parts with different width as well as ruling out parking lots from the asphalt class map. This spatial spectral joint approach we propose here is capable of building up a road network connectivity graph and this graph lays a foundation for further road related tasks.

8390-68, Session 14

Fusing stereo and multispectral data from WorldView-2 for urban modeling

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Using the capability of WorldView-2 to acquire very high resolution (VHR) stereo imagery together with as much as eight spectral channels allows the worldwide monitoring of any built up areas, like cities in evolving states. In this paper we show the benefit of generating a high resolution digital surface model (DEM) from multi-view stereo data (PAN) and fusing it with pan sharpened multi-spectral data to arrive at very detailed information in city areas.. The fused data allow accurate object detection and extraction and by this also automated object oriented classification and change detection applications. The methods proposed in this paper exploit the full range of capacities provided by WorldView-2, which are the high agility to acquire a minimum of two but also more in-orbit-images with small stereo angles, the very high ground sampling distance (GSD) of about 0.5 m and also the full usage of the standard four multispectral channels blue, green, red and near infrared together with the additional provided channels special to WorldView-2: coastal blue, yellow, red-edge and a second near infrared channel. From the very high resolution stereo panchromatic imagery a digital surface model (DSM) is derived using the semi global matching (SGM) method developed at DLR. In the first step this method generates so called disparity images fitting exactly on one of the stereo input images and contains the pixelwise distances - a kind of parallax - to the stereo partner image. Since these disparity images fit exactly on the input images the musltispectral data may be used for optimization. Therefore for each of the stereo images a pan-sharpened multispectral image is generated which serves as basis for a spectral classification. By using the classification result the disparity image is corrected and finally an improved DSM can be generated. Based on this high resolution DSM - with in fact nearly the same ground sampling distance as the imagery - individual ortho images for each of the stereo input images can be derived. Also a digital terrain model (DTM) is extracted from the DSM containing only the height information of the ground without elevated objects like buildings or trees. Through a combined usage of DSM, DTM and the multispectral ortho images an advanced urban classification can be achieved. Based on this classification a more sophisticated fully 3D extraction of urban objects is possible. If such datasets from different times are generated the possibility of an expert object based change detection (in quasi 3D space) and automatic surveillance becomes possible. By presenting results of some experiments using the developed methodologies, the full potential of the approach is documented.

8390-69, Session 14

Detection of compound structures using a Gaussian mixture model with spectral and spatial constraints

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Recently available multi-spectral information in very high spatial resolution (VHR) images acquired from new generation satellites has enabled new applications. However, the increasing amount of detail in these images also necessitates new advanced algorithms for automatic analysis. For example, the commonly used classification algorithms that require a pre-segmentation of the image into homogeneous regions cannot always cope with the increasing complexity because such homogeneous regions often correspond to very small details.

This paper describes a new approach that combines statistical and structural characteristics of simple objects to discover compound structures in VHR images. The compound structures of interest include different types of residential, commercial, industrial, and agricultural areas that are comprised of spatial arrangements of primitive objects such as buildings, roads, and trees corresponding to locally homogeneous details. The proposed approach uses a probabilistic representation of the image content by providing a robust extension to the commonly used Gaussian mixture models (GMM). In this model, each pixel is represented using a feature vector that encodes both spectral and spatial information consisting of the pixel's multi-spectral data and its coordinate, respectively. Then, each Gaussian component in the GMM models a group of pixels corresponding to a particular object where the spectral mean corresponds to the color of the object, the spectral covariance corresponds to the homogeneity of the color content, the spatial mean corresponds to the position of the object, and the spatial covariance models its shape.

Given example compound structures of interest that are comprised of multiple primitive objects (e.g., several buildings, road segments, vegetation patches), a new learning algorithm adapts a GMM to the image data by robustly fitting Gaussian components to these objects and marking other areas as outliers. The algorithm can also incorporate spatial constraints on the layout of the primitive objects in terms of their relative positions within the compound structure. Then, the learned model can be used to detect similar structures in other parts of the same image or in other images by grouping pixels that have high likelihoods of belonging to the Gaussian object models while satisfying the spatial layout constraints. Experiments using WorldView-2 data show that the proposed method can detect high-level compound structures that cannot be modeled using traditional techniques.

8390-70, Session 15

Assessing the impact of background spectral graph construction techniques on the topological anomaly detection algorithm

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Anomaly detection algorithms have historically been applied to hyperspectral imagery in order to identify pixels whose material content is incongruous with the background material in the scene. Typically, the application involves extracting man-made objects from natural and agricultural surroundings. A large challenge in designing these algorithms is determining which pixels initially constitute the background material within an image. The topological anomaly detection (TAD) algorithm constructs a graph theory-based, fully non-parametric topological model of the background in the image scene, and uses codensity to measure deviation from this background. In TAD, the initial graph theory structure of the image data is created by connecting an edge between any two pixel vertices x and y if the Euclidean distance between them is less than some resolution r. While this type of proximity graph is among the most well-known approaches to building a geometric graph based on a given set of data, there are a wide variety of different geometrically-based techniques. In this paper, we present a comparative test of the performance of TAD across four different constructs of the initial graph: density weighted k-nearest neighbors, k-nearest neighbors plus the minimum spanning tree, adaptive sigma-local graphs, and the proximity graph originally implemented in TAD.

8390-71, Session 15

Anomaly and target detection by means of non-parametric density estimation

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We describe A novel completely non parametric high-dimension density estimation algorithm suited for anomaly and target detection using hyperspectral imaging.

The new algorithm is compared against linear matched filter detection schemes with different available sample sizes, background statistics (MVN, GMM and non Gaussian) and within the scope of closed-loop CFAR operation. The new algorithm is shown to be superior in important cases.

8390-72, Session 15

Target detection in hyperspectral imagery with singular covariance matrices

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Accurate covariance matrix estimation for high dimensional data can be a difficult problem. A good approximation of the covariance matrix needs in most cases a prohibitively large number of pixels, i.e. pixels from a stationary section of the image whose number is greater than several times the number of bands. Estimating the covariance matrix with a number of pixels that is on the order of the number of bands or less will cause, not only a bad estimation of the covariance matrix, but also a singular covariance matrix which cannot be inverted. In this article we will investigate two methods to give a sufficient approximation for the covariance matrix while only using a small number of neighboring pixels. The first is the QLRX (Quasilocal Covariance Matrix RX algorithm) that uses the eigenvectors of a global set of points, coming from a non-stationary distribution, but eigenvalues of the local neighborhood. The second method is SMT (Sparce Matrix Transform) that performs a set of K Givens rotations to estimate the covariance matrix. We will compare results from target acquisition that are based on both of these methods. An improvement for the SMT algorithm is suggested.

8390-73, Session 15

Simultaneous spectral/spatial detection of edges for hyperspectral imagery: the HySPADE algorithm revisited

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The hyperspectral/spatial detection of edges (HySPADE) algorithm, originally published in 2004 [1], has been modified and applied to a wider diversity of hyperspectral imagery (HSI) data. As originally described in [1], HySPADE operates by converting the naturally two-dimensional edge detection process based on traditional image analysis methods into a series of one-dimensional edge detections based on spectral angle. The HySPADE algorithm: i) utilizes spectral signature information to identify edges; ii) requires only the spectral information of the HSI scene data and does not require a spectral library; iii) facilitates simultaneous use of all spectral information; iv) does not require endmember or training data selection; v) does not require spectral matching against a library; vi) generates multiple, independent data points for statistical analysis of detected edges; vii) is robust in the presence of noise; and viii) may be applied to radiance, reflectance, and emissivity data--though it is applied only to reflectance spectra (and their principal components transformation) in this report. HySPADE has recently been modified to use Euclidean distance values as an alternative to spectral angle. It has also been modified to use an N-pixel x N-pixel sliding window in contrast to the 2004 version which operated only on spatial subset image chips. HySPADE results are compared to those obtained using traditional (Roberts and Sobel) edge-detection methods. Spectral angle and Euclidean distance HySPADE results are superior to those obtained using the traditional edge detection methods; the best results are obtained by applying HySPADE to the higher-order, information-containing bands of principal components transformed data (both radiance and reflectance). However, in practice, both the Euclidean distance and spectral angle versions of HySPADE should be applied and their results compared. HySPADE results are shown; extensions of the HySPADE concept are discussed as are applications for HySPADE in HSI analysis and exploitation particularly in the era of ground-based HSI sensors that are capable of producing very high spatial resolution, photograph-like imagery.

[1] Resmini, R.G., (2004). Hyperspectral/Spatial Detection of Edges (HySPADE): An algorithm for spatial and spectral analysis of hyperspectral information. Proceedings of the SPIE, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery X, S.S. Shen and P.E. Lewis, eds., Orlando, Fla., April 12-16, v. 5429, doi: 10.1117/12.541877, pp. 433-442.

8390-74, Session 15

Autonomous target-dependent waveband selection for tracking in performance-driven hyperspectral sensing

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Performance-driven sensing is a promising new concept that relies on sensing, processing, and exploiting only the most “decision-relevant” sets of target data for the purpose of reducing requirements on data collection, processing, and communications. An example of a device supporting such a concept is a MEMS-based single pixel Fabry-Perot spectrometer being developed at the Rochester Institute of Technology, which can record selected wavelengths on a per-pixel basis throughout an image. This paper presents an autonomous target-dependent waveband selection approach for performance-driven sensing with an adaptive hyperspectral imaging sensor. Given a target that is to be tracked, a subset of wavebands is estimated from locally recorded hyperspectral data that provides optimal target detectability against local background. The waveband selection algorithm relies on finding a subset of bands that provides the minimum Bhattacharyya coefficient between a target histogram and local background histogram constructed from the respective bands. To illustrate the concept, we perform a simulation study for vehicle tracking with a set of synthetic DIRSIG rendered HSI images. The simulations demonstrate improved vehicle tracking accuracy when using the adaptively-selected subset of wavebands for tracking by histogram matching compared to performing tracking by histogram matching with regular (fixed) color bands. We extend the framework to a dynamic concept where the waveband subset is updated over time as a function of changes in local target background and discuss the full integration of the Feature-Aided Tracking component derived from the selected wavebands within a multiple hypothesis tracking (MHT) framework.

8390-75, Session 15

Application specific band selection with multivariate methods of analysis for a-Si:H multispectral photodiodes

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In the recent past the generation and processing of multispectral data have had an immense impact on optical characterization systems. Typically carried out with a resolution of 10nm, the measurements are time-intensive, generate a lot of data, and are largely redundant.

In this paper we present a band selection routine. To examine which bands provide a high information density, a virtual test environment is used. The photocurrent j = ∫ E(λ)*Sabs(λ)*r(λ) dλ was calculated for different light sources E, spectral response curves Sabs (bands), and the reflectance r of whitish powder samples that were suspected to be dangerous or illegal. Whether we can gain any knowledge from this the multivariate data set will have to be determined. The employed factor analysis is a common method in the group of structure-discovering methods, and provides good results in the discovery of connections between parameters. It is used particularly if a variety of parameters must be reduced for a certain question. For the verification, a dimension of the external separation must be defined. For this an n-dimensional vector P must be assigned to each measurement, that is registered in the matrix M. To determine the volume V of this dot cloud, the dimension normalized volume is defined as ∆CL = sqrt (4^n-3/5^4 * sqrt (V = det MT * det M)), where n is the quantity of employed bands.

The use of such optimized multispectral photodiodes would simplify and accelerate the identification of potentially dangerous substances for civil security and defense applications.

8390-76, Session 15

A new compact representation of morphological profiles: report on first massive VHR image data processing at the JRC

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The paper shows the results of an experiment involving several thousand of VHR image scenes in input and an image processing task involving multiscale morphological description of the image features. Because the multi-scale morphological decomposition schema is involving a comprehensive set of scales (512 scales) in VHR image data set, then the amount of data in output would be unacceptable for data storage and information mining purposes. The paper then introduces the use of a new compact and simple representation of image multi-scale morphological decomposition based on three descriptors calculated from the discrete derivative of the morphological profile (DMP): namely the morphological characteristic C, saliency S and level L. In this paper, the words “morphological profile” (MP) and then DMP are used as general concept summarizing any image differential multi-scale decomposition schema based on morphological connected operators such as opening and closing by reconstruction or area opening and closing. The new CSL model is conceived to radically reduce dimensionality of DMP descriptors while keeping the relevant image information that can be used for further classification, information mining or automatic recognition tasks. The reference scenario is the use of CSL-reduced set of a complete DMP set of descriptors in case of image information retrieval tasks requiring massive multiple scene satellite image processing. The proposed CSL model reduces DMP dimensionality with a statistical-model-free approach that can be potentially applied for multiple-scene automatic information retrieval tasks. This is because CSL model avoids clustering based on actual statistical distribution of DMP features in the specific scene under process. CSL model can be potentially extended to any morphological multi-scale decomposition scheme based on connected operators such as area-based morphological decompositions and recently-defined differential attribute profiles (DAP), or extended to the multispectral domain. The paper introduces also a new colour composition based on the mapping of CSL model in the RGB space trough a hue-saturation-value (HSV) transform. This new CSL-HSV colour model may allow fast visual mining of the image information contents. After introducing the CSL formulas, the paper shows some examples of CSL model outputs on different satellite images potentially liked to different application areas. Moreover, some interesting uses of the CLS outputs are suggested with examples including image information mining and image segmentation tasks.

8390-77, Session 16

Remote sensing of shorelines using data fusion of hyperspectral and multispectral imagery aquired from mobile and fixed platforms

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This paper presents recent results obtained from airborne and vessel mounted hyperspectral and fixed platform multispectral sensors that have been used for imaging littoral zones in Florida and the northern Gulf of Mexico waters. The results demonstrate the use of HSI-MS fused synthetic imagery for anomaly and feature detection along shorelines in surface and subsurface waters. Imagery presented makes use of hyperspectral imagery using an integrated, calibrated sensing system developed by the author, with integrated GPS and IMU sensor data, along with simultaneously collected multiband MS imagery. Optimal bands are selected using the Weber contrast and multiband contrast algorithms for target and feature detection in aquatic environments. HSI sensor data calibration and pushbroom image corrections using Kalman filtering of GPS and inertial motion unit (IMU) signals are described and the techniques used to correct the pushbroom imagery for platform motions is presented. Application to anomaly detection of weathered oil in coastal and nearby marshes demonstrate that imagery can be fused and synthetic spectra for 1-5 mm can be used for feature detection in marshes, and along shorelines. Techniques are also shown whereby the spectral-spatial sharpening of the fused imagery can be tested using synthetic line targets as well as actual ground targets for spectral anomaly detection and optimal band selection based upon absorption and backscatter spectral regions.

8390-78, Session 16

Integration of heterogeneous data for classification in remote sensing imagery

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As new remote sensing modalities emerge, it becomes increasingly important to find more suitable algorithms for fusion and integration of different data types for the purposes of target/anomaly detection and classification. Typical techniques that deal with this problem are based on performing detection/classification separately in chosen modalities, and then integrating the resulting outcomes into a more complete picture. In this paper we propose a new approach, based on creating a novel fused representation of the multi-modal data, which is then subject to analysis by means of the state-of-the-art classifiers. The imaging modalities which we shall incorporate include hyperspectral imagery, bathymetry data, as well as spatial information. Our approach involves machine learning techniques based on analysis of joint data-dependent graphs and their associated diffusion kernels. Then, the significant eigenvectors of the derived fused graph Laplace operator form the new representation, which provides integrated features from the heterogeneous input data. We analyze the role of different metrics in each imaging modality, for the purpose of providing optimal classification in the fused representation. We also investigate the role of compressive sensing techniques and divide-and-conquer strategies for lowering the computational complexity of the aforementioned methods, which becomes essential in dealing with fused data.

8390-79, Session 16

SpecTIR hyperspectral airborne Rochester experiment data collection campaign

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A multi-modal (hyperspectral, LiDAR, and multi-spectral) imaging data collection campaign was conducted at the Rochester Institute of Technology (RIT) in conjunction with SpecTIR Incorporated in the Rochester, New York, area July 26 - 29, 2010. The campaign was titled the SpecTIR Hyperspectral Airborne Rochester Experiment (SHARE) and collected data in support of nine simultaneous unique experiments, several of which leveraged data from multi-modalities. Airborne imagery was collected over the city of Rochester with hyperspectral, multispectral, and Light Detection and Ranging (LiDAR) imagers. Sites for data collection included the Genesee River, sections of downtown Rochester, and the RIT campus. Experiments included sub-pixel target detection, water quality monitoring, thermal vehicle tracking and wetlands health assessment. An extensive ground truthing effort was accomplished an addition to the airborne imagery collection. The ultimate goal of this comprehensive data collection campaign was to provide a community sharable resource that would support additional experiments. This paper details the experiments conducted and the corresponding data collected in conjunction with this campaign.

8390-80, Session 16

IMAGESEER: images for science, education, experimentation and research: a NASA database of benchmark images for image processing teaching and research

J. J. Le Moigne, T. G. Grubb, B. C. Milner, NASA Goddard Space Flight Ctr. (United States)

A number of web-accessible databases, including medical, military or other image data, offer universities and other users the ability to teach or research new Image Processing techniques on relevant and well-documented data. However, NASA images have traditionally been difficult for researchers to find, are often only available in hard-to-use formats, and do not always provide sufficient context and background for a non-NASA Scientist user to understand their content.

The new IMAGESEER (IMAGEs for Science, Education, Experimentation and Research) database seeks to address these issues. Through a graphically-rich web site for browsing and downloading all of the selected datasets, benchmarks, and tutorials, IMAGESEER provides a widely accessible database of NASA-centric, easy to read, image data for teaching or validating new Image Processing algorithms. As such, IMAGESEER fosters collaboration between NASA and research organizations while simultaneously encouraging development of new and enhanced IP algorithms.

The first prototype (http://imageseer.nasa.gov) includes a representative sampling of NASA multispectral and hyperspectral images from several Earth Science instruments, along with a few small tutorials. Some of the image processing techniques are cloud detection, image registration, and map cover/classification. For each technique, corresponding data are selected from four different geographic regions; mountains, urban, water coastal, and agriculture areas. Satellite images have been collected from several instruments - Landsat-5 and -7, Earth Observing -1 (EO-1) Advanced Land Imager (ALI) and Hyperion, and the Moderate Resolution Imaging Spectroradiometer (MODIS). After georegistration, these images are available in common formats such as GeoTIFF and raw formats, along with associated benchmark data.

8390-81, Session 17

Using DIRSIG to identify uniform sites and demonstrate the utility of the side-slither calibration technique for Landsat's new pushbroom sensors

A. Gerace, J. R. Schott, S. D. Brown, M. G. Gartley, Rochester Institute of Technology (United States)

The next generation of Landsat satellites (LDCM) is scheduled for launch in December, 2012 and, in a departure from traditional design, will carry two new pushbroom imagers; the nine band Operational Land Imager (OLI) and the two band Thermal Infrared Sensor (TIRS). Previous efforts focused on using the DIRSIG (Digital Imaging and Remote Sensing Image Generation) tool to simulate all the phenomena that can lead to non-uniformity variations in an LDCM image. This includes detector-to-detector and array-to-array non-uniformities due to variations in relative spectral response (RSR), gain, bias, and non-linearities. Synthetic images were generated to predict the LDCM performance pre-launch and to identify calibration concerns.

In support of the calibration effort for LDCM, this work expands on an on-orbit calibration technique called Side-Slither. In this technique, a 90 degree yaw maneuver is performed over a uniform region in an effort to determine a flat-field correction. The first component of this research uses Landsat 5 radiance images as input to DIRSIG to evaluate potential sites for LDCM to perform Side-Slither once it achieves orbit. Relative gains are calculated and compared over desert regions, the Amazon, water regions, and Antarctica in an effort to identify suitable sites for the maneuver. The second component of this work uses the DIRSIG tool to model all the non-uniformity variations from previous efforts and to perform the Side-Slither technique in an effort to calibrate the raw data. Synthetic image data is used and presented to measure the potential value of this calibration technique.

8390-82, Session 17

On-orbit radiometric calibration of Earth-observing sensors using the radiometric calibration test site (RadCaTS)

J. S. Czapla-Myers, N. P. Leisso, N. J. Anderson, S. F. Biggar, College of Optical Sciences, The Univ. of Arizona (United States)

Vicarious techniques are used to provide supplemental radiometric calibration data for sensors with onboard calibration systems, and are increasingly important for sensors without onboard calibration systems. The Radiometric Calibration Test Site (RadCaTS) is located at Railroad Valley, Nevada. It is a facility that was developed with the goal of increasing the amount of ground-based radiometric calibration data that are collected annually while maintaining the current level of radiometric accuracy produced by traditional manned field campaigns. RadCaTS is based on the reflectance-based approach, and currently consists of a Cimel sun photometer to measure the atmosphere, a weather station to monitor meteorological conditions, and seven ground-viewing radiometers (GVRs) that are used the determine the surface reflectance throughout the 1×1-km area. The data from these instruments are used in MODTRAN5 to determine the at-sensor spectral radiance at the time of overpass.

This work describes the RadCaTS concept, the instruments used to obtain the data, and the processing method used to determine the surface reflectance and top-of-atmosphere spectral radiance. A discussion on the design and calibration of three new eight-channel GVRs is introduced, and the surface reflectance retrievals are compared to in-situ measurements. Radiometric calibration results determined using RadCaTS are compared to Landsat 7 ETM+ and imaging sensors onboard the Terra spacecraft.

8390-83, Session 17

Tracking nonuniformity in the thermal infrared sensor through pre-launch measurements and simulated on-orbit data

M. Montanaro, Sigma Space Corp. (United States) and NASA Goddard Space Flight Center (United States); A. D. Gerace, Rochester Institute of Technology (United States)

The Thermal Infrared Sensor (TIRS) will continue thermal band measurements of the Earth for the Landsat Data Continuity Mission (LDCM). The instrument is a dual-channel, pushbroom imager that consists of 1850 detector elements per band spanning the 15-degree cross track field of view. The pushbroom configuration of the instrument presents several challenges to ensure that the instrument meets uniformity and linearity requirements across the field of view. Each detector element may have a slightly different spectral and radiometric response resulting from variations in pixel-to-pixel gain, bias, and spectral band shape. These differences must be measured and corrected for in order to provide a radiometrically accurate data product necessary for the Landsat science mission.

During pre-launch testing, calibration ground support equipment (CGSE) is used to uniformly illuminate the TIRS field of view with various source radiances. Calibration routines are created to convert the raw detector signal from these uniform sources into accurate at-sensor radiances. During the on orbit life of the instrument, vicarious calibration techniques such as the side-slither method may be used to check the pixel-to-pixel uniformity. To demonstrate the value of this technique for TIRS, the Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool is utilized to simulate on orbit TIRS data. Appropriate sites on the Earth are identified and side-slither data is generated. The simulated on orbit data is then compared to pre-launch calibration data to determine whether this calibration approach is viable to track the calibration of TIRS over its orbital lifetime.

8390-84, Session 17

Evaluation of nighttime imaging limits of visible near-infrared earth observation platforms

A. D. Gerace, M. G. Gartley, Rochester Institute of Technology (United States)

A subset of the existing NASA and NOAA families of earth observation imaging platforms currently on orbit (Landsat 7, Advanced Land Imager, and the Defense Meteorological Satellite Program Operational Line Scanner) have a primary mission of imaging the earth's landforms during the daylight hours. All three systems are capable of nighttime imaging operations, however this capability of Landsat and ALI is not frequently utilized due to lack of utility in the resulting data products. Many researchers have published science results on focused problems such as volcanic eruptions, wildfires, and urban settlement mapping. In this work we present a first-principles based radiometric framework for quantifying the capability of such imaging platforms for detecting the presence of boats in open waters taking into consideration the interaction between the boat and water surfaces. The low-level radiometric modeling is performed using both the DIRSIG software tool and MODTRAN, in conjunction with freely available boat geometric models, incandescent lamp spectra, and a randomly roughened sea surface geometry. The resulting performance metric represents the minimum wattage of one or more incandescent illuminants that might be detected above the system noise floor for a variety of imaging geometries.

8390-85, Session 17

Simulation and experimental results of a chromotomographic hyperspectral imager

C. Su'e, M. Hawks, B. Yao, Air Force Institute of Technology (United States)

A field-deployable chromotomographic hyperspectral imager has been developed and tested as a risk-reduction prototype to assist design of a space-based system. The instrument uses a high-speed video camera looking through rotating direct-vision prism to simultaneously observe the full field of view in all wavelength channels. This enables hyperspectral imaging of transient events at high temporal resolution. Spatial, spectral and temporal resolution have been characterized in laboratory and field experiments, and results are compared to physics-based model predictions. The models are then used to analyze future trade-space choices for design of the space-based system.

8390-86, Session 17

Tradeoff between misregistration and resampling in design of spectral imaging sensors

T. Skauli, Norwegian Defence Research Establishment (Norway)

In spectral imaging, it is well known that coregistration errors can lead to large errors in the recorded spectra. Such errors are minimized through optics design, but many sensors exhibit a significant degree of misregistration. A newly proposed metric for coregistration error (T. Skauli, Proc. SPIE 8158) has been shown to give an upper bound on the error (T. Skauli, submitted). Here, this metric is used to determine the optimal resampling for several model cases of spatial coregistration error. The residual spectral error after resampling is analyzed. In the limit of a sensor with a large coregistration error, even a doubling of the pixel width in the resampling may be insufficient to obtain data where the error is comparable to the noise. Thus a difficult tradeoff exists between coregistraion and spatial resolution in sensor design. Other aspects of resampling are also discussed. For example, there may be a preference for placing resampled pixels on an irregular spatial grid if that enables an improvement in the coregistration performance of resampled data.

8390-87, Session 18

Euclidean commute time distance embedding and its application to spectral anomaly detection

J. A. Albano, D. Messinger, Rochester Institute of Technology (United States)

Spectral image analysis problems often begin by applying a transformation that generates an alternative representation of the spectral data with the intention of exposing hidden features not discernable in the original space. In this paper, a transformation based on a Markov-chain model of a random walk on a graph is introduced with the application of exposing anomalies in the data. The random walk is quantified by a measure known as the average commute time distance which is the average length a random walker takes, when starting at one node, to transition to another and return to the starting node. The Euclidean Commute Time Distance (ECTD) transformation embeds the nodes of a graph in a Euclidean space such that their separation is equal to the square root of the commute time distance. This distance metric has the important characteristic of increasing when the number of paths between two nodes decreases and the lengths of those paths increase. Therefore, the ECTD is a similarity measure between nodes of a graph that takes into account both distance and graph connectivity. Contained in this paper is a discussion of the proximity graph built on the spectral data, the properties of the ECTD, a subspace projection that approximately preserves its maximum variance and a discussion of the performance of anomaly detection in the ECTD space.

8390-88, Session 18

Statistical methods for chemical plume identification and false alarm mitigation

A. Lai, Northeastern Univ. (United States); S. Golowich, D. Manolakis, MIT Lincoln Lab. (United States)

The utility of passive hyperspectral imaging spectrometers for the remote sensing of chemical vapor plumes in the long-wave infrared (LWIR) atmospheric window is well established for a variety of military and civilian tasks. A number of aspects of the real-world application of this technology remain challenging, however, including the reliable identification of gas species and assignment of a confidence metric to gases that are identified. A closely related problem is that of false alarm mitigation, i.e. the identification of detections as not corresponding to a known threat chemical.

The basis of most chemical plume signal processing algorithms is the linear dependence on the gas concentrations of the at-sensor radiance contrast due to the plume, when the plumes are optically thin. In the language of linear models, the identification problem corresponds to that of model selection, and confidence metrics, along with false alarm mitigation, are related to assessments of goodness of fit. In this contribution, we assess the utility of a number of model selection algorithms derived from the statistical regression literature to this remote plume sensing application. Through application to a variety of simulated and experimentally measured data sets, we identify regions of parameter space that can be reliably handled, as well as those in which challenges remain.

8390-89, Session 18

Algorithms for remote quantification of chemical plumes: a comparative study

S. Niu, Northeastern Univ. (United States); S. Golowich, D. Manolakis, MIT Lincoln Lab. (United States)

Passive remote imaging of chemical vapors in the long-wave infrared (LWIR) atmospheric window enables the detection, identification, and quantification of the plume. Of these data products, quantification is the most challenging to obtain, due to the sensitive non-linear dependence of the at-sensor radiance on the relevant parameters and the near non-identifiability of the model in certain parameter regimes. Here, we will focus on estimation of the mean concentration-path length product. This parameter may be combined with geometric information to yield information on the absolute quantities of gas present.

The plume quantification problem may be approached from multiple angles, corresponding to a variety of physical effects that may be exploited. Accordingly, a diversity of statistical quantification algorithms has been proposed in the literature, ranging in complexity from linear regression to Bayesian Markov-chain Monte Carlo methods. The ultimate performance and algorithmic complexity of each is influenced by the assumptions made about the scene, which may include the presence of ancillary measurements or particular background / plume features that may or may not be present. In this paper, we evaluate a number of quantification algorithms on the basis of effects exploited, performance relative to the theoretical limits, and computational complexity. The results are useful for the design of future algorithms tuned to particular sensor geometries and classes of scene backgrounds.

8390-90, Session 18

Comparative evaluation of hyperspectral anomaly detectors in different types of background

D. C. Borghys, Royal Belgian Military Academy (Belgium); I. Kåsen, Norwegian Defence Research Establishment (Norway); V. Achard, ONERA (France); C. Perneel, Royal Belgian Military Academy (Belgium)

Anomaly detection in hyperspectral data has received a lot of attention for various applications. The aim of anomaly detection is to detect pixels in the hyperspectral data cube whose spectra differ significantly from the background spectra.

Many anomaly detectors have been proposed in literature. They differ by the way the background is characterised and by the method used for determining the difference between the current pixel and the background (single-component Gaussian background model).

The most well-known anomaly detector is the RX detector that calculates the Mahalanobis distance between the pixel under test and the background.

Different variations on the RX detector have been proposed.

Anomaly detection methods based on multi-component background models have also been introduced. These are particularly useful in areas with a highly structured background.

In this paper representative examples of these two families of anomaly detectors are selected and applied to a database of hyperspectral images acquired in different types of background (agricultural areas, forests, urban areas, sea).

A comparative evaluation of results is presented and discussed.

8390-91, Session 18

Target detection in hyperspectral images: a comparative study of ICA and other algorithms

K. C. Tiwari, Bharati Vidyapeeth's College of Engineering (India); M. K. Arora, D. P. Singh, Indian Institute of Technology Roorkee (India)

Hyperspectral data acquired over hundreds of narrow contiguous wavelength bands is extremely suitable for target detection but requires spectral modeling using a priori available target spectra, a condition difficult to meet in practice. It therefore necessitates algorithms which do not depend upon target spectra for target detection. Independent component analysis (ICA), an evolving new technique that aims at finding out components which are statistically independent or as independent as possible, can be extended for target detection as it does not have any requirement of a priori availability of target spectra. A comparative assessment of target detection for hyperspectral images using ICA versus various other target detection algorithms therefore assumes significant interest. The aim of this paper is to compare ICA based algorithm with four spectral matching algorithms namely, Orthogonal Subspace Projection (OSP), Constrained Energy Minimisation (CEM), Spectral Angle Mapper (SAM) and Spectral Correlation Mapper (SCM), and four anomaly detection algorithms namely, OSP anomaly detector (OSPAD), Reed-Xiaoli anomaly detector (RXD), Uniform Target Detector (UTD) and a combination of Reed-Xiaoli anomaly detector and Uniform Target Detector (RXD-UTD) for target detection. A set of synthetic and AVIRIS hyperspectral data containing aircrafts as targets were used for the experiments. A comparison of true positive and false positive rates of target detections obtained from ICA and other algorithms plotted on a receiver operating curves (ROC) space indicates superior performance of ICA over other algorithms.

8391-01, Session 1

Hybrid methodology for the detection, tracking, and classification of humans in difficult infrared video imagery

J. R. Bonick, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The detection, tracking, and classification of humans in video imagery is of obvious military and civilian importance. The problem is difficult under the best of circumstances. In infrared imagery, or any grayscale imagery, the problem is compounded by the lack of color cues. Sometimes, human detection in IR imagery can take advantage of the thermal difference between humans and background-but this difference is not robust. Varying environmental conditions regularly degrade the thermal contrast between humans and background. In difficult data, humans can be effectively camouflaged by their environment and standard feature detectors are unreliable.

The research described here uses a hybrid approach toward human detection, tracking, and classification. The first is a feature-based correlated body parts detector. The second is a pseudo-Hough transform applied to the edge images of the video sequence. The third relies on an optical flow-based vector field transformation of the video sequence. This vector field permits a multidimensional application of the feature detectors initiated in the previous two methods. Then a multi-dimensional oriented Haar transform is applied to the vector field to further characterize potential detections, in effect creating a robust multi-dimensional template. The three methods are combined via a conditional voting scheme to effectively detect and track humans at various scales and poses in difficult IR video imagery. In addition, the hybrid formulation is shown to provide a broader characterization of human activity that can be used to classify human activity patterns and human intent. The innovation of this research is the multi-dimensional oriented Haar transform, supplemented by feature detectors.

8391-02, Session 1

Improving FLIR ATR performance in a turbulent atmosphere with a moving platform

B. J. Schachter, D. D. Baumgartner, Northrop Grumman Electronic Systems (United States)

Forward Looking InfraRed (FLIR) automatic target recognition (ATR) systems depend upon the capacity of the atmosphere to propagate thermal radiation over long distances. To date, not much research has been conducted on analyzing and mitigating the effects of the atmosphere on FLIR ATR performance, even though the atmosphere is often the limiting factor in long-range stationary target detection and recognition. A turbulent atmosphere can also cause frame-to-frame inconsistencies in the scene, affecting the ability to detect and track moving targets. When image quality is limited by turbulence, increasing the aperture size or improving the focal plane array cannot improve ATR performance. Traditional single frame image enhancement does not solve the problem.

A new approach is described for reducing the effects of turbulence. It is implemented under a lucky-region-imaging framework using short integration time and spatial domain processing. It is designed to preserve important target and scene structure. Unlike previous Fourier-based approaches originating from the astronomical community, this new approach is intended for real-time processing from a moving platform, with ground as the background. The system produces a video stream with minimal delay.

A new video quality measure (VQMturb) is presented for quantifying the success of turbulence mitigation on real data when reference imagery is unavailable. The VQMturb is the core of the innovation because it allows a wide range of algorithms and their variations to be quantitatively compared. An algorithm can be chosen, and then tuned, to best-fit available processing power, latency requirements, scenarios and sensor characteristics.

8391-03, Session 1

Time series modeling for automatic target recognition

A. U. Sokolnikov, Visual Solutions and Applications (United States)

Time series modeling is proposed for identification of targets whose images are not clearly seen. The model building takes into account air turbulence, precipitation, fog, smoke and other factors obscuring and distorting the image. The complex of library data (of images, etc.) serving as a basis for identification provides the deterministic part of the identification process, while the partial image features, distorted parts, irrelevant pieces and absence of particular features comprise the stochastic part of the target identification. The missing data approach is elaborated that helps the prediction process for the image creation or reconstruction. The results are provided.

8391-05, Session 1

Robust automatic target recognition in FLIR imagery

Y. Soyman, Roketsan A.S. (Turkey)

In this paper, a robust automatic target recognition algorithm in FLIR imagery is proposed. Target is first segmented from background using wavelet transform. Segmentation process is accomplished by parametric Gabor wavelet transformation. Invariant features belonging to target, which is segmented from the background, are then extracted via moments. Higher-order moments, while providing better quality for identifying the image, are more sensitive to noise. A trade-off study is then performed on a few moments that provide effective performance. Bayes method is used for classification, using Mahalanobis distance as the Bayes' classifier. Phase-correlation method and normalized cross correlation are also used for similarity metrics. Results are assessed based on false alarm rates. The proposed method is shown to be robust against rotations, translations and scale effects. Moreover, it is shown to effectively perform under low-contrast objects in FLIR images. Performance comparisons are also performed on both GPU and CPU. Results indicate that GPU has superior performance over CPU.

8391-06, Session 1

Seeing through degraded visual environment

F. A. Sadjadi, Lockheed Martin Maritime Systems & Sensors (United States)

In this paper we develop novel techniques for enhancing images and classifying ground targets from airborne vehicles, whose signatures are distorted by turbulence and environmental distortions such as dust, fog, and smoke.

8391-07, Session 2

TBD (Keynote)

J. C. Ricklin, Air Force Research Lab. (United States)

No abstract available

8391-08, Session 2

Detection of dielectric objects using polarimetric invariants in forward-looking ground penetrating radar

C. S. Chun, E. H. Y. Chun, Physics Innovations Inc. (United States)

Ground penetrating radar (GPR) is often used for the detection of landmines but is limited by low signal-to-clutter ratios. We built and tested a forward-looking polarimetric GPR which measured the scattering matrix of targets for frequencies 1.35-2.14 GHz. From the scattering matrix we calculated the target's polarizability angle, relative phase angle, and target magnitude. These quantities are invariant to rotations about the sensor-to-target axis. Our measurements were made on dry sand without a target, on a polystyrene cylinder (height 7 cm, diameter 26 cm, dielectric constant ~2.5) buried 2 in under the surface of the sand, and a styrofoam cylinder (height 4.8 cm, diameter 25.1 cm, dielectric constant ~1.0) buried 2 in under the surface of the sand. In all cases, horizontal polarization was reflected more than vertical and the polarizability angle varied from 10 to 35 deg with the larger values at lower frequencies. The difference in target magnitudes for the sand alone and the sand with the polystyrene cylinder was 7% over the frequency range. The difference for sand alone and sand with the styrofoam cylinder was 16%. As the frequency is swept over the frequency range the relative phase for sand alone changed by 2π. However, when either target was buried in the sand, the relative phase changed more rapidly, by approximately 6π over the same range. From this observation we conclude that the change of relative phase over frequency may be a useful feature for detecting plastic objects and voids in sand.

8391-09, Session 2

Analysis of vehicle vibration sources for automatic differentiation between gas and diesel piston engines

K. J. Sigmund, S. Shelley, Etegent Technologies, Ltd. (United States)

Vibration signatures sensed from distant vehicles using laser vibrometry systems provide valuable information that may be used to help identify key vehicle features such as engine type, engine speed, and number of cylinders. While developing algorithms to blindly extract the aforementioned features from a vehicle's vibration signature, it was shown that detection of engine speed and number of cylinders was more successful when utilizing a priori knowledge of the engine type, gas or diesel piston, and optimizing algorithms for each engine type. In practice, implementing different algorithms based on engine type first requires an algorithm to determine whether a vibration signature was produced by a gas piston or diesel piston engine. This paper provides a general overview of the observed differences between datasets from gas and diesel piston engines, and proceeds to detail the current method of differentiating between the two. To date, research has shown that basic signal processing techniques can be used to distinguish between gas and diesel vibration datasets with reasonable accuracy for piston engines of different configurations running at various speeds.

8391-10, Session 3

Locating emitters using a cross-spectral cross-ambiguity function (CSCAF)

D. J. Nelson, National Security Agency (United States)

The conventional cross-ambiguity function (CAF) is frequently used to resolve the source location of a radio signal received by two or more moving receivers. In using the CAF, the received signals are modeled as a time and frequency shifted representation of the transmitted signal. The time difference of arrival (TDOA) and frequency difference of arrival (FDOA) of the signal received by two or more moving receivers are estimated from the CAF surface, and the location of the transmitter is estimated as the intersection of the iso-chron (curve of constant TDOA) and iso-Dopp (curve of constant FDOA.) In this process, the phase of the surface is discarded, and only the magnitude of the CAF surface is used. We introduce a cross-spectral cross-ambiguity function (CSCAF) and apply it to the emitter location problem. The CSCAF is computed as the product of the complex-valued CAF and the complex conjugate of the CAF surface delayed in TDOA. In this representation, the magnitude of the CSCAF is essentially the energy of the conventional CAF, and the argument of the CSCAF is an un-quantized representation of the FDOA computed as the phase of the complex-valued CAF differentiated with respect to TDOA. The advantage of the CSCAF is that it provides an extremely accurate estimate of FDOA. We demonstrate use of the CSCAF in estimating emitter location more accurately than can be attained by the conventional CAF process.

8391-11, Session 3

Radar target recognition using non-cooperative scatterer matching game

I. I. Jouny, Lafayette College (United States)

This paper utilizes game-theoretic principles in the automatic recognition of unknown radar targets. This study uses a non-cooperative matching game where pure strategies are associated with specific items to be matched, and agreement between competing hypotheses represents the payoff gained when playing a certain strategy against an opponent who is playing another strategy. The target recognition approach attempts to match scattering centers of an unknown target with those of library targets as competing strategies. The algorithm is tested using real radar data representing scattering from commercial aircraft models. Radar data of library targets at various azimuth positions are matched against an unknown radar target signature at a specific aspect angle. Computer simulations provide an estimate of the error rates in scenarios of additive Gaussian noise corrupting target signatures. The game has been recently effectively used in matching image objects (image recognition) [1]. Researchers in [1] used this game with vast evolutionary dynamics to achieve many-to-many matching in a manner where evolutionary stable states (ESS) represented a solution to the matching problem. This paper adapts the algorithm developed in [1] to radar target recognition of non-cooperative target.

[1] Albarelli A., Bulo S., Torsello A., and Pellilo M., "Matching as a non-cooeprative game", IEEE 12th international conference on Computer Vision, pp. 1319-1326, 2009.

8391-12, Session 3

Maritime target identification in flash-ladar imagery

W. Armbruster, M. Hammer, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Automatic identification of naval vessels using focal plane array laser radar imagery presents a number of challenges involving water reflections, intensity-dependent range errors, partial occlusions, and low signal detection probabilities. 3D models of boats and ships are not readily available and may be inaccurate and incomplete; in particular, passengers on the boat cannot be incorporated into the 3D model.

In the paper each 3D ship model is generated automatically from a single range image, using the fact that ships have a vertical symmetry plane passing through the bow tip. Manual interaction is required only for selecting an appropriate range image and verifying the modeling results.

3D model matching is probabilistic, based on the range error distribution, correspondence errors, the detection probability of potentially visible model points and false alarm errors. The match algorithm is

robust against incomplete and inaccurate models as well as imaging errors. Computation time is minimized by reducing the number of pose hypotheses to be verified. This involves segmentation of water reflections, hull segmentation, bounding box estimation, bow direction determination and corner point localization.

A discrimination accuracy of about 96% was attained, using a maritime database with over 8000 Flash laser radar images of 146 ships at various ranges and orientations together with a model library of 46 vessels. Computation time on a single processor is approximately 0.1 sec per frame and model.

8391-13, Session 4

Dispersion-invariant features for classification of objects from their acoustic backscatter in a range-dependent channel

V. T. Gomatam, P. J. Loughlin, Univ. of Pittsburgh (United States)

In littoral environments, the acoustic backscatter from targets of interest changes with propagation, owing to interactions of the sound with the ocean bottom and surface. These propagation-dependent changes in the backscatter can negatively impact classification of objects because the target echo changes with distance. In previous works, features invariant to the propagation effects of dispersion and absorption in range-independent channels were developed. In this work we derive features that are invariant to range-dependent dispersion and verify through simulations their superior classification performance compared to the previously developed range-independent features, as well as to ordinary temporal moments.

8391-14, Session 4

Relating two probability distributions and an application to the Rayleigh distribution

L. Cohen, Hunter College (United States)

The standard method for relating an arbitrary distribution to a Gaussian distribution are the Gram-Charlier and Edgeworth series. We generalize these methods and relate any two probability distributions by a non-linear transformation. The advantage of our formulation is that the starting distribution does not have to be Gaussian. We apply this method to relate the Rayleigh distribution to other noise distributions in a systematic way.

8391-15, Session 4

The scintillation index for reverberation noise

L. Cohen, A. Ahmad, Hunter College (United States)

The standard scintillation index is an important measure in understanding reverberation because it gives one a sense of how a distribution differs from Rayleigh. We argue that since the noise is changing with position and time the scintillation index should also be a function of space and time. To be able to define a space-time SI and we have calculated the relevant moments. By calculation and simulation we show how a random sequence of pulses propagating in a dispersive medium approaches Rayleigh.

8391-16, Session 5

Automated recognition challenges for wide-area motion imagery

K. L. Priddy, Air Force Research Lab. (United States)

No abstract available

8391-17, Session 5

ATR solutions for a single class using affine transformations on a union of subspaces model

C. F. Hester, U.S. Army Research, Development and Engineering Command (United States)

The solution of a single class target recognition problem is created using affine transformation of the solution space. An extension of the union of subspaces model is developed and related to the null space of the target/clutter design matrix for a linear particular solution. This particular solution is used to find affine transformations for a subspace factorization of the solution space yielding the general ATR solutions. The theory is shown to provide unique solutions for a target class.

8391-18, Session 5

Spatio-temporal features for tracking and quadruped/biped discrimination

R. Rickman, D. C. Bamber, Waterfall Solutions Ltd. (United Kingdom)

Techniques such as SIFT and SURF facilitate efficient and robust image processing operations through the use of sparse and compact spatial feature descriptors and show much potential for defence and security applications. WS have extended this technique to include information from the temporal domain to improve its utility in applications involving moving platforms and dynamic scenes within video data. We demonstrate how the proposed spatio-temporal descriptors are very effective as the basis of a target tracking and discriminator system which can distinguish between bipeds (humans) and quadrupeds (animals). This discrimination is based on the relative movements of non-rigid body parts in addition to the spatial characteristics of the targets. The ability to reliably classify moving targets can significantly enhance a base protection system, since it would enable a significant reduction of false alarms, whilst maintaining the quickest possible response times. Results using sequences of video imagery with walking humans and dogs show that the proposed spatio-temporal feature descriptors offer potential for enhancing the performance of moving target classifiers. With a simple classifier we have demonstrated improved classification performance using the combined spatio-temporal features over spatial or temporal features alone. The potential use of spatio-temporal features for human behaviour classification is also discussed. This would allow CCTV operators to more rapidly identify acts of violence or civil disorder. The utilisation of spatio-temporal features can also aid in the tracking and re-acquisition of suspicious individuals, who might appear indistinguishable from others within a given frame, but relinquish their identity through distinctive motion.

8391-19, Session 5

Robust model-based object recognition using a dual-hierarchy graph

I. Weiss, Univ. of Maryland, College Park (United States)

We have implemented a general purpose, robust system for object representation and recognition. The system is model-based and knowledge-based, with knowledge derived from analysis of objects and images, unlike many of the current methods which rely on generic statistical inference. This knowledge is intrinsic to the objects themselves, based on geometric and semantic relations among objects. Therefor the system is insensitive to external interferences such as viewpoint changes (scale, pose etc.), illumination changes, occlusion, articulation, shadows, camouflage, sensor noise etc. It also handles the variability in the object itself, before even taking the image, such as when mounting a machine gun on a pick-up truck or when a vehicle is damaged. While

this knowledge is specific to the domain of imagery, it is general within the image domain, being based on intrinsic properties of shapes. This enables our method to combine high-level object semantics with low-level image processing, and to be independent of the source of the image such as EO, IR, LADAR, radar etc., or even CAD models. We represent all available models in a graph containing two independent but interlocking hierarchies. One of these intrinsic hierarchies is based on parts, e.g. a truck has a cabin, a trunk, wheels etc. The other hierarchy we call the "Level of Abstraction (LOA), e.g. a vehicle is more abstract than a truck, a rectangle is more abstract than a door. This enables us to represent and recognize generic objects just as easily as specific ones. A new algorithm for traversing our graph, combining the advantages of both top-down and bottom-up strategies, has been implemented.

8391-20, Session 5

Improved watercraft detection in short-wave infrared imagery using tailored sparse representations

C. C. Olson, Sotera Defense Solutions, Inc. (United States); K. P. Judd, U.S. Naval Research Lab. (United States); K. Chander, A. J. Smith, V Systems, Inc. (United States); M. Conant, J. Nichols, U.S. Naval Research Lab. (United States)

We present a semi-supervised technique for small watercraft detection in a littoral environment characterized by the presence of multiple targets and both land- and sea-based clutter. The detector correlates a sparse signal model acquired from previous imagery with newly acquired scenes. A given pixel is considered a target if the output of the sparse model exceeds a given threshold. Signal models considered herein include wavelets, overcomplete dictionaries, and combinations thereof. A direct search optimization routine (differential evolution) is used to learn a signal model that improves the average probability of detection for a fixed false alarm rate on an ensemble of training images. The resulting signal model is shown to improve detection on a set of test images previously unseen by the algorithm. In the wavelet-only case, the weights governing a linear combination of simple wavelets are tailored such that average detection is improved relative to any of the individual wavelets. Detection performance for standard (e.g. Haar, cosine) and learned (using K-SVD) overcomplete dictionaries is also considered. Finally, differential evolution is used to search the space of parameters governing a parameterized wavelet model for a wavelet that provides the overcomplete dictionary that best improves average detection on the ensemble of test images. Receiver operating characteristic (ROC) curves are generated to illustrate performance in all cases.

8391-21, Session 5

Multicue object detection and tracking for security in complex environments

U. Ahsan, S. A. Sattar, NED Univ. of Engineering and Technology (Pakistan); H. Noor, Technische Univ. München (Germany); M. Zafar, Georgia Institute of Technology (United States)

Efficient moving object tracking requires near flawless detection results to establish correct correspondences between frames. This is especially true in the defense sector where accuracy and speed are critical factors of success. However, problems such as camera motion, lighting and weather changes, texture variation and inter-object occlusions result in misdetections or false positive detections which in turn, lead to broken tracks. In this paper, we propose to use background subtraction and an optimized version of Horn & Schunk's optical flow algorithm in order to boost detection response. We use the frame differencing method, followed by morphological operations to show that it works in many scenarios and the optimized optical flow technique serves to complement the detector results. The Horn & Schunk's method yields color-coded motion vectors for each frame pixel. To segment the moving regions in the frame, we apply color thresholding to distinguish the blobs. Next, we extract appearance-based features from the detected object and establish the correspondences between objects' features, in our case, the object's centroid. We have used the Euclidean distance measure to compute the minimum distances between the centroids. The centroids are matched by using Hungarian algorithm, thus obtaining point correspondences. The Hungarian algorithm's output matrix dictates the objects' associations with each other. We have tested the algorithm to detect people in corridor, mall and field sequences and our early results with an accuracy of 86.4% indicate that this system has the ability to detect and track objects in video sequences robustly.

8391-22, Session 5

High-range-resolution (HRR) ATR via non-negative matrix approximations

V. R. Riasati, MacAulay-Brown, Inc. (United States); U. Srinivas, V. Monga, Pennsylvania State Univ. (United States)

Principal Component Analysis (PCA) is widely used in building a reduced dimension basis from a set of statistically representative training data samples. The PCA sub-space construction has been successfully applied to Automatic Target Recognition (ATR) using high range resolution (HRR) profiles (Bhatnagar et al, ICASSP 1998) in the form of eigen-templates. This set of "orthogonal eigen-vectors" built in PCA while very effective for compression can often lead to loss of discriminative information in signals which could be useful for distinguishing between signal classes. In this work, we use training HRR profiles that span the various target classes and build a new basis set via a recent linear algebra advance known as non-negative matrix approximations (NNMAs) - which involves an explicit non-negativity constraint. The fundamental insight is that owing to underlying physics, we expect non-negative basis and an accompanying non-negative coefficient set to be a more accurate generative model for HRR profiles than the PCA basis which lacks direct physical interpretation. The NNMA basis vectors while not orthogonal capture discriminative local components of HRR profiles which offer much greater discriminative capability. We test the merits of the NNMA basis representation for Automatic Target Recognition (ATR) using high range resolution (HRR) profiles. Features for classification are extracted by projecting the HRR profile vectors onto the NNMA basis sub-space. The feature vectors are then fed into a support vector machine (SVM) classifier which performs the eventual class assignment. For multi-class ATR, the SVMs are trained in a one-versus-all manner.

8391-23, Session 5

Sensor agnostic object recognition using a map seeking circuit

T. L. Overman, Lockheed Martin Space Systems Co. (United States); M. Hart, Hart Scientific Consulting International L.L.C. (United States)

Automatic object recognition capabilities are traditionally tuned to exploit the specific sensing modality they were designed to. Their successes (and shortcomings) are tied to object segmentation from the background, they typically require highly trained personnel to train them, and they become cumbersome with the introduction of new objects. In this paper we describe a sensor independent algorithm based on the biologically inspired technology of map seeking circuits (MSC) which overcomes many of these obstacles. In particular, the MSC concept offers transparency in object recognition from a common interface to all sensor types, analogous to a USB device. It also provides a common core framework that is independent of the sensor and expandable to support high dimensionality decision spaces. Ease in training is assured by using commercially available 3D models from the video game community. The search time remains linear no matter how many objects are introduced, ensuring rapid object recognition. Here, we report results of an MSC algorithm applied to object recognition and pose estimation from high range resolution radar (1-D), electro-optical imagery (2-D), and

LIDAR (3-D) separately. This sensor-agnostic approach, and the MSC architecture itself, are ideally suited to a natural fusion of heterogeneous data streams.

8391-24, Session 6

Image reconstruction and target acquisition through compressive sensing

M. M. Suttinger, Univ. of Central Florida (United States); R. R. Muise, Lockheed Martin Missiles and Fire Control (United States)

Compressive imaging is an emerging field which allows one to acquire far fewer measurements of a scene than a standard pixel array and still retain the information contained in the scene. One can use these measurements to reconstruct the original image or even a processed version of the image. Recent work in compressive imaging from random convolutions is extended by relaxing some model assumptions and introducing the latest sparse reconstruction algorithms. We then compare image reconstruction quality of various convolution mask sizes, compression ratios, and reconstruction algorithms. We also expand the algorithm to derive a pattern recognition system which operates of a compressively sensed measurement stream. The developed compressive pattern recognition system reconstructions the detections map of the scene without the intermediate step of image reconstruction. A case study is presented where pattern recognition performance of this compressive system is compared against a full resolution image.

8391-25, Session 6

The incredible shrinking covariance estimator

J. Theiler, Los Alamos National Lab. (United States)

Covariance estimation is a key step in many target detection algorithms. To distinguish target from background requires that the background be well-characterized. This applies to targets ranging from the precisely known chemical signatures of gaseous plumes to the wholly unspecified signals that are sought by anomaly detectors. When the background is modelled by a (global or local) Gaussian or other elliptically contoured distribution (such as Laplacian or multivariate-t), a covariance matrix must be estimated. The standard sample covariance overfits the data, and when the training sample size is small, the target detection performance suffers.

Shrinkage addresses the problem of overfitting that inevitably arises when a high-dimensional model is fit from a small dataset. In place of the (overfit) sample covariance matrix, a linear combination of that covariance with a fixed matrix is employed. The fixed matrix might be the identity, the diagonal elements of the sample covariance, or some other underfit estimator. The idea is that the combination of an overfit with an underfit estimator can lead to a well-fit estimator. The coefficient that does this combining, called the shrinkage parameter, is generally estimated by some kind of cross-validation approach, but direct cross-validation can be computationally expensive.

This paper extends an approach suggested by Hoffbeck and Landgrebe, and presents a more efficient algorithm for finding the leave-one-out cross-validation (LOOCV) estimate of the shrinkage parameter used in estimating the covariance matrix from a limited sample of data.

8391-26, Session 6

Design and implemention of a wireless geophone sensor node for target detection and classification

M. Zubair, K. Hartmann, Univ. Siegen (Germany)

Target detection and classification is very crucial in wireless sensor networks for outdoor security applications. This paper presents a novel design and implemention of a wireless geophone sensor node to detect and further discriminate dynamic targets (Persons and Vehicles) in wireless sensor network. The design of a sensor node is based on a tiny Overo Fire computer-on-module made by Gumstix that can communicate via wireless and a high resolution analog-to-digital converter intended for seismic monitoring applications.

The basic concept to detect and classify a target lies in the idea to consider an individual footstep of a person and/or motion of a vehicle detects as an event in the detection range of the geophone. Thus, an event is defined by two parameters: start time and end time of an event. The time difference between the event start and the event end is used to classify objects. An individual footstep of a person e.g. generates an event of approximately 250 msec time length in quiet environment. This time length decreases when the environment is noisy or a person is far away from the geophone. In case of vehicle, the time length of an event depends on its motion and the maximum detection range of the geophone for the vehicle. These unique characteristics are not only used to detect, but also used to classify a target.

The adaptive wavelet denoising algorithm is applied in real-time to extract a target signal from the real noisy envirnoments. This algorithm adjusts the threshold based on the energy of the wavelet series coefficients. Then, the energy monitoring detector based on Order-Statistic Constant False Alarm Rate (OS-CFAR) is applied to detect events. These extracted events are further used to classify a person or a vehicle.

The paper will demonstrate that the lower cost and the higher processing capabilites of a wireless geophone sensor node provides promising results to detect and classify targets for outdoor security application.

8391-27, Session 6

Feature-level fusion of multiple target detection results in hyperspectral image based on RX detector

X. Sun, B. Zhang, Ctr. for Earth Observation and Digital Earth (China); L. Yang, Institute of Remote Sensing Applications (China); L. Gao, W. Zhang, Ctr. for Earth Observation and Digital Earth (China)

Target detection is an import application of hyperspectral remote sensing, which can find specific targets from hyperspectral images on the premise that the target spectral is known. Lots of algorithms have been proposed for this application, mainly including CEM, ACE, AMF, ECD, OSP, et al. All these algorithms need a detector (or vector function) to calculate a statistic value for each pixel, which represents the probability of specific target contained in a pixel on some assumption relevant to certain algorithms, and then, detection results will be obtained by thresholding segmentation of statistic values. In the process of thresholding, high detection rate leads to high false alarm rate. Reducing false alarm rate while ensure high detection rate is an import task of target detection research. Considering the different false alarms resulted in different algorithms, this paper tries to reduce false alarm rate by fusing different detection results. A statistic value produced by a target detection algorithm, the gray image with the same size of original image, was considered as the original image's feature; and a new multi-bands image named feature image can be obtained by combining these features. In this image, pixels containing targets have big value in all bands; pixels not containing targets have small value in all bands; and pixels with false alarm have big value in some bands. Using RX algorithm to detecting anomaly in feature images can effectively make pixels with big value in all bands stand out. After thresholding the statistic result obtained by RX, feature-level fusion of multiple target detection results can be complete.

Monday-Wednesday 23-25 April 2012

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8392-01, Session 1

Bayesian filtering in electronic surveillance

S. P. Coraluppi, C. A. Carthel, Compunetix, Inc. (United States)

Fusion of passive electronic support measures (ESM) with active radar data enables tracking and identification of platforms in air, ground, and maritime domains. An effective multi-sensor fusion architecture adopts hierarchical real-time multi-stage processing. This paper focuses on the recursive filtering challenges.

The first challenge is to achieve effective platform identification based on noisy emitter type measurements; while optimal processing is computationally infeasible, a good suboptimal solution is available via a sequential measurement processing approach. The (suboptimal) scan-based approach employs the usual assumption in most target tracking paradigms (save for the probabilistic multiple hypothesis tracker, or PMHT): each scan contains at most one detection per target. Unfortunately, this assumption is violated in ESM data, where multiple emissions from the same target are possible. Thus, the scan-based approach that considers one measurement at a time considerably simplifies the filtering solution as well as the overall multi-target tracking logic, while maintaining good performance.

The second challenge is to process waveform feature measurements to enable disambiguation in multi-target scenarios. While the Kalman filter approach is somewhat coarse in that it replaces piecewise-constant dynamics with linear dynamics with equivalent process noise. We improve upon the solution by considering explicitly the underlying Markov jump dynamics of the process. We consider two hypotheses at each stage of processing: (1) the underlying waveform parameter has not changed, and (2) the underlying waveform parameter has changed. Both hypotheses are scored and the likelier one is selected. In the latter case, we reinitialize the filter based on the latest measurement.

8392-02, Session 1

Statistical efficiency of simultaneous target and sensors localization with position dependent noise

R. W. Osborne III, Y. Bar-Shalom, Univ. of Connecticut (United States); L. M. Kaplan, J. George, U.S. Army Research Lab. (United States)

This work derives the Cramer-Rao lower bound (CRLB) for an acoustic target and sensor localization system in which the noise characteristics depend on the location of the source. The system itself has been previously examined, but without deriving the CRLB and showing the statistical efficiency of the estimator used. Two different versions of the CRLB are derived, one in which range measurements are available (`full-position CRLB"), and one in which only direction of arrival measurements are available (`bearing-only CRLB"). In both cases, the estimator is found to be statistically efficient; but, depending on the sensor-target geometry, the range measurements may or may not significantly contribute to the accuracy of target localization.

8392-03, Session 1

Expected track length estimation using track break statistics

P. O. Arambel, L. Finn, BAE Systems (United States)

Expected Track Length (ETL) is a measure of performance that indicates the ability of a tracker to maintain track for extended periods of time. The most desirable method for computing ETL would involve the use of large sets of real data with accompanying truth. This accurately accounts for sensor artifacts and data characteristics, which are difficult to simulate. However, datasets with these characteristics are difficult to collect because the coverage area of the sensors is limited, the collection time is limited, and the number of targets that can realistically be truthed is also limited. Thus when using a real dataset, many tracks are terminated because the objects leave the field of view or the end of the dataset is reached. This induces a bias in the estimation when the ETL is computed directly from the tracks. An alternative to direct ETL computation is the use of Markov-Chain models that use track break statistics to estimate ETL. This method provides unbiased ETL estimates from datasets of any length and size. In this paper we extend previous work in this area deriving an explicit expression of the ETL as a function of track break statistics. A number of examples illustrate the properties and advantages of the method.

8392-04, Session 1

Multiple model tracking for multitarget multi-Bernoulli filters

D. Dunne, T. Kirubarajan, McMaster Univ. (Canada)

The Multitarget Multi-Bernoulli (MeMBer) filter is a recursive, multitarget tracking mechanism based on Random Finite Set (RFS) theory using the Finite Set Statistics (FISST) framework. Similar to other RFS methods, it provides an estimate of both the number of targets present in a given scenario space along with the most likely location of those targets. It also provides this estimate without the expensive operation of multidimensional assignment between measurements and targets estimates. Unlike other RFS methods, the MeMBer filter outputs an estimate of the actual multitarget probability density function. This approximation is composed of individual Bernoulli sets that essentially partition the surface into individual state estimates. Each Bernoulli estimate contains the likelihood of a states existence as well as its probability distribution function. The MeMBer filter has been derived using both a nonlinear Sequential Monte Carlo (SMC) approximation as well as an analytical solution using Gaussian Mixture based approximations. Both of these approximations have been implemented and tested against simulated data and have been shown to be viable multitarget tracking solutions.

Similar to previous RFS filters, the basic MeMBer derivations are mainly for tracking targets traveling under a single motion model and do not account for a targets ability to maneuver during the estimation process. This paper will introduce a new MeMBer recursion for tracking targets traveling under multiple motion models. The proposed multiple model MeMBer (MM-MeMBer) filter uses Jump Markov Models (JMM) to extended the basic MeMBer recursion to allow for multiple target motion models. This extension is implemented using both the SMC and GM based MeMBer approximations. The recursive prediction and update equations are presented for both implementations. Each multiple model implementation is validated against its respective standard MeMBer implementation as well as against each other. This validation is done using a simulated scenario containing multiple maneuvering targets. A variety of metrics are observed including estimate accuracy, model detection capability and algorithm computational efficiency.

8392-05, Session 1

Improved multitarget tracking in clutter with ambiguous Doppler measurements

G. Zhou, McMaster Univ. (Canada) and Harbin Institute of Technology (China); M. Pelletier, FLIR Systems Ltd. (Canada); T.

Kirubarajan, McMaster Univ. (Canada)

Doppler measurements, which can be exploited to improve tracking performance, are also available in addition to position measurements in many tracking systems. Due to filter stability and performance issues, accuracy improvements from incorporating Doppler measurements into the state estimator, using nonlinear filters such as the extended Kalman filter (KF) and the unscented KF, are not guaranteed. As a consequence, for target tracking in clutter, either the utilization of Doppler measurements is limited, or the benefit from Doppler measurements is not assured. In this paper, a new state estimator, which avoids nonlinear filtering by enhancing information with two linear Kalman filters while extracting information outside filtering recursions, is employed to modify the multitarget tracking system. In addition, another modification is made to deal with the problem of Doppler ambiguity, which is common in pulse Doppler radars. In the ambiguous case, each original measurement is replaced by a set of hypothetic measurements, with identical position measurements and different Doppler values. Doppler components are used under a multiple hypotheses tracking (MHT) frame in the same way as the position components to update target states and association probabilities recursively. False hypothetic measurements and clutter are discriminated automatically by the modified association scheme with the additional constraint that only one of the hypothetic measurements originated from the target. Comparisons between the cases of ambiguous Doppler, unambiguous Doppler and position-only measurement are performed in multitarget tracking scenarios. It is demonstrated that the proposed method can deal with Doppler ambiguity well and yields significant performance improvement by exploiting ambiguous Doppler measurements. Comparison of Doppler ambiguity handling at tracking level vs. at detection level is also presented in this paper.

8392-06, Session 2

Overview of performance assessment of multitarget tracking algorithms

E. P. Blasch, Air Force Research Lab. (United States); C. Yang, Sigtem Technology, Inc. (United States); I. Kadar, Interlink Systems Sciences, Inc. (United States); G. Chen, I-Fusion Technologies, Inc. (United States); L. Bai, Temple Univ. (United States)

There are hosts of target tracking algorithm approaches, each valued with respect to the scenario operating conditions (e.g. sensors, targets, and environments). Due to the application complexity, no algorithm is general enough to be widely applicable, nor is a scenario narrow enough for a tailored algorithm. Thus, to meet real world goals, multitarget tracking (MTT) algorithms need to undergo performance assessment for (1) bounding performance over various operating conditions, (2) managing expectations and applicability for user acceptance, and (3) understanding the constraints and supporting information for reliable and robust performance. To meet these challenges, performance assessment should strive for three goals: (1) challenge problem scenarios with a rich variety of operating conditions, (2) a standard, but robust, set of metrics for evaluation, and (3) design of experiments for sensitivity analysis over parameter variation of models, uncertainties, and measurements.

8392-07, Session 2

Evaluation of tracking methods for maritime surveillance

Y. Fischer, M. Baum, Karlsruher Institut für Technologie (Germany); F. Flohr, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); U. Hanebeck, Karlsruher Institut für Technologie (Germany); J. Beyerer, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany) and Karlsruher Institut für Technologie (Germany)

In many surveillance applications, the tracking of possible targets is an essential part of the whole system. The performance of the tracking algorithm has direct influence on the quality of higher level tasks like automatic threat detection or abnormal behavior detection. In this article, we present an evaluation of different algorithms to get the best assignment between new observations and estimated tracks. Especially in situations with closely moving targets, this association step is crucial for tracking performance. Therefore we examined multiple scenarios from the maritime domain with targets moving close to each other or having crossing trajectories. We chose well known algorithms such as the Joint Integrated Probabilistic Data Association (JIPDA), Linear Multi Target PDA and Linear Joint PDA. Furthermore we examined an instance of the Monte Carlo Markov Chain Data Association (MCMCDA). The algorithms have been implemented and integrated into a flexible data fusion architecture for maritime surveillance. We extended the system by an evaluation module, allowing us to identify pros and cons of these different algorithms. Using the evaluation module, it was possible to compare the algorithms directly based on the chosen performance measures. Here we used already approved extensions of the Optimal Subpattern Assignment, which have not been applied to above-named algorithms before. Also further performance measures are used to get a single score for each algorithm. As no single algorithm is equally well fitted to all tested scenarios, our results show which algorithms fits best for specific scenarios.

8392-08, Session 2

Simulation of large-scale multitarget tracking scenarios using GPUs

Y. Dinath, R. Tharmarasa, McMaster Univ. (Canada); E. Meger, exactEarth Ltd. (Canada); P. Valin, Defence Research and Development Canada, Valcartier (Canada); T. Kirubarajan, McMaster Univ. (Canada)

The increased availability of Graphical Processing Units (GPUs) in personal computers has made parallel programming worthwhile, but not necessarily easier. This paper will take advantage of the power of a GPU, in conjunction with the Central Processing Unit (CPU), in order to simulate target trajectories for large-scale scenarios such as wide-area maritime or ground surveillance. The idea is to simulate the motion of tens of thousands of targets using a GPU by formulating an optimization problem that maximizes the throughput. To do this, the proposed algorithm is provided with input data that describes how the targets are expected to behave, path information (e.g., roadmaps, shipping lanes), and available computational resources. Then, it is possible to break down the algorithm into parts that are done in the CPU vs. those sent to the GPU. The ultimate goal is to compare processing times of the algorithm with a GPU in conjunction with a CPU to those of the standard algorithms running on the CPU alone. In this paper, the optimization formulation for utilizing the GPU, simulation results on scenarios with a large number of targets and conclusions are provided.

8392-09, Session 2

Dynamic optimization of ISR sensors using a risk-based reward function applied to ground- and space-surveillance scenarios

J. T. DeSena, S. R. Martin, J. C. Clarke, A. J. Newman, The Johns Hopkins Univ. Applied Physics Lab. (United States)

As the number and diversity of sensing assets available for intelligence, surveillance and reconnaissance (ISR) operations continues to expand, the limited ability of human operators to effectively manage, control and exploit the ISR ensemble is exceeded, leading to reduced operational effectiveness. Automated support both in the processing of voluminous sensor data and sensor asset control can relieve the burden of human operators to support operation of larger ISR ensembles. In dynamic environments it is essential to react quickly to current information to

avoid stale, sub-optimal plans. Our approach is to apply the principles of feedback control to ISR operations, "closing the loop" from the sensor collections through automated processing to ISR asset control.

Previous work by the authors demonstrated non-myopic multiple platform trajectory control using a receding horizon controller in a closed feedback loop with a multiple hypothesis tracker applied to multi-target search and track simulation scenarios in the ground and space domains. This paper presents extensions in both size and scope of the previous work, demonstrating closed-loop control, involving both platform routing and sensor pointing, of a multi-sensor, multi-platform ISR ensemble tasked with providing situational awareness and performing search, track and classification of multiple moving ground targets in irregular warfare scenarios. The closed-loop ISR system is fully-realized using distributed, asynchronous components that communicate over a network. The closed-loop ISR system has been exercised via a networked simulation test bed against a scenario in the Afghanistan theater implemented using high-fidelity terrain and imagery data. In addition, the system has been applied to space surveillance scenarios requiring rapid reacquisition of maneuvered objects and other stressing conditions where current deliberative, manually intensive processes for managing sensor assets are insufficiently responsive. Simulation experiment results are presented.

The algorithm to jointly optimize sensor schedules against search, track, and classify is based on recent work by Papageorgiou and Raykin on risk-based sensor management. It uses a risk-based objective function and attempts to minimize and balance the risks of misclassifying and losing track on an object. It supports the requirement to generate tasking for metric and feature data concurrently and synergistically, and account for both tracking accuracy and object characterization, jointly, in computing reward and cost for optimizing tasking decisions.

8392-10, Session 2

Utilizing information-based sensor management to reduce the power consumption of networked unattended ground sensors

K. Hintz, George Mason Univ. (United States)

Information based sensor management (IBSM) has been previously developed to maximize the amount of valued information collected by a heterogeneous set of sensors on a sensor platform to maximally reduce the valued uncertainty in an estimate of the situation as maintained in a local situation awareness database. There is a current need to extend the lifetime of unattended container security sensors which can be part of an ad-hoc network. A particular example of an unattended ground sensor containing GPS, acoustic, seismic, PIR, and magnetic detectors has been analyzed as a sensor platform and used to demonstrate this ability to increase sensor operational lifetime. These sensors have been reduced to their sensor functions which are listed in an applicable function table (AFT) and these functions have been mapped to managed evidence nodes in a situation information expected value network (SIEV-net) developed for this application. Reduced power consumption has been realized by the collaboration of these networked sensors with overlapping sensor capabilities when containers are clustered. A description of the adaptation of IBSM to networked unattended ground sensors is presented along with performance results from a simple field demonstration of clustered and an unclustered containers.

8392-11, Session 2

GMTI radar resource management: performance of monotone parameterized policies

B. Balaji, Defence Research and Development Canada, Ottawa (Canada)

The problem considered in this paper is that of scheduling the beam of an agile ground moving target indication (GMTI) radar that is tracking several GMTs. In this paper, a two time-scale radar management scheme--comprising of a (longer time-scale) micromanager and a (shorter time scale) micromanager-- is investigated. Recent work has demonstrated that under certain conditions (that are also practically reasonable), the optimal micromanager can be expressed as monotone parameterized policies that can then be solved efficiently in real-time. It is demonstrated using simulations that the performance is better and more robust compared to a basic periodic policy scheduler.

8392-12, Session 3

The random set approach for processing nontraditional measurements is rigorously Bayesian

R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); A. I. El-Fallah, Scientific Systems Co., Inc. (United States)

In several previous publications the first author has proposed a "generalized likelihood function" (GLF) approach to processing nontraditional measurements such as attributes, features, natural-language statements, and inference rules. The GLF approach is based on random set "generalized measurement models" for nontraditional measurements. GLFs are not conventional likelihood functions, since they are not density functions and their integrals are usually infinite, rather than equal to 1. For this reason, it has been unclear whether or not the random set GLF approach is fully rigorous from a strict Bayesian point of view.

In a recent paper, the first author demonstrated that the GLF of a specific type of nontraditional measurement-quantized measurements-is rigorously Bayesian. In this paper we show that this result can be generalized to arbitrary nontraditional measurements, thus removing any doubt that the GLF approach is rigorously Bayesian.

8392-13, Session 3

Spline probability hypothesis density filter

R. Sithiravel, R. Tharmarasa, McMaster Univ. (Canada); M. McDonald, Defence Research and Development Canada, Ottawa (Canada); M. Pelletier, FLIR Systems Ltd. (Canada); T. Kirubarajan, McMaster Univ. (Canada)

The Probability Hypothesis Density Filter (PHD) is a multiple target tracker for recursively estimating the number of targets and their state vectors from a set of observations. This filter is capable of working well with an environment containing false alarms and missed detections. Two distinct PHD filter implementation algorithms have been developed: Gaussian Mixture Probability Hypothesis Density (GM-PHD) and Sequential Monte Carlo Probability Hypothesis Density (SMC-PHD) filters.

The SMC-PHD filter uses particles to provide target state estimates, which can lead to inaccurate estimates and high computational requirements whereas the GM-PHD filter does not use particles, but restricts to linear Gaussian target models. The SMC-PHD filter technique provides only weighted samples at discrete points in the state space instead of a continuous estimate of the probability intensity function of the system state and thus suffers from the well-known degeneracy problem.

This paper proposes a B-Spline based Probability Hypothesis Density (S-PHD) filter, which has the capability to model any arbitrary probability intensity function. The resulting algorithm can handle linear, non-linear, Gaussian, non-Gaussian dynamics and it can also provide continuous estimates of the probability density function of the system state.

In addition, by moving the knots dynamically, the S-PHD filter ensures that the splines cover only the region where the probability of the system state is significant, hence the high efficiency of the S-PHD filter is maintained at all times. Also, unlike the SMC-PHD filter, the S-PHD filter is free from degeneracy problems due to its continuous nature. The S-PHD filter derivations and simulations are provided in this paper.

8392-14, Session 3

The classification-aided cardinalized probability hypothesis density (CA-CPHD) tracker

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Mahler introduced a new approach to tracking in which target states and measurements are modeled as random finite sets. The resulting Probability Hypothesis Density (PHD) filter propagates the first-moment approximation to the multi-target Bayesian posterior distribution.

The follow up Cardinalized PHD (CPHD) filter is a recursive filter that propagates both the posterior likelihood of (an unlabeled) target state and the posterior cardinality density (probability mass function of the number of targets).

In this work, we integrate target class information into the data association process of the CPHD filter, i.e. modification of the update step for the bin probabilities is necessary. The sensor's classification capability is modeled by a confusion matrix. The new filter is accompanied by a track management scheme dealing with events such as track initiation, update and deletion along with mode pruning and merging.

We test the new tracker on two simulated sonar datasets: in the first scenario, two targets are moving in parallel, while in the second scenario the two targets cross tracks. Metrics of performance are reported, such as track probability of detection, track fragmentation, number of false tracks and RMSE. The improvements brought forth by the classification aided version of the CPHD over the original CPHD filter are highlighted in the presence of association uncertainty in the kinematic measurements.

8392-15, Session 3

Sensor management for tracking multiple ballistic missiles

A. I. El-Fallah, A. Zatezalo, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); R. K. Mehra, Scientific Systems Co., Inc. (United States)

Accurate and robust tracking of multiple missile trajectories using a network of dispersed and disparate sensors that include radars and EO/IR, is a challenging problem. Missile trajectory uncertainties, multisensor detection constraints, and measurement stochasticity has to be modeled and tested for robust performance.

For centralized multisensor multitarget tracking, we apply the multisensor multitarget Posterior Expected Number of Targets of Interest (PENTI) sensor management objective function to dynamically estimate the optimal dwelling of sensors on targets. Each sensor can be tasked either individually or jointly, that is we either perform an un-coordinated or a coordinated sensor management. The un-coordinated sensor management allows for the estimation and tasking of each sensor at its location, whereas the coordinated sensor management estimates sensor parameters (e.g. where to direct the field of view of each sensor) at a central location and distributes or communicates the corresponding tasks to each sensor at its own location.

Both sensor management approaches are implemented and tested using the PENTI objective function and multitarget densities. The performance of the two resulting algorithms are compared and tested against different multisensor multitarget scenarios.

8392-16, Session 3

Multiple model particle filter for missile tracking

A. Zatezalo, A. I. El-Fallah, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); R. K. Mehra, Scientific Systems Co., Inc. (United States)

Accurate tracking of a missile in its ascending phase is a challenging problem due to a variety of encountered uncertainties in the boost phase accelerations, in the booster transition times, and in the booster separation forces.

In addition, different types of geographically dispersed sensors need to be utilized in a seamlessly integrated fashion to ensure adequate track maintenance for both the missile and its generated debris.

A multiple model particle filter is developed, implemented, and tested to address this challenging problem. The filtering algorithm is derived using nonlinear filter methodology and the theory of finite-state time-nonhomogeneous Markov processes.

Preliminary results obtained using a one-stage simulation testbed are presented and discussed.

8392-17, Session 3

Multivehicle decentralized fusion and tracking

A. I. El-Fallah, A. Zatezalo, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); R. K. Mehra, Scientific Systems Co., Inc. (United States)

We introduce a decentralized fusion and tracking based on a distributed multi-source multitarget filtering and robust communication with the following features: (i) data reduction; (ii) a disruption tolerant dissemination procedure that takes advantage of storage and mobility; and (iii) efficient data set reconciliation algorithms.

We developed and implemented complex high-fidelity marine application demonstration of this approach that encompasses all relevant environmental parameters. In the simulated example, multi-source information is fused by exploiting sensors from disparate Unmanned Underwater Vehicles (UUV) and Unmanned Surface Vehicle (USV) multi-sensor platforms.

Communications among the platforms are continuously establishing and breaking depending on the time-changing geometry. We compare and evaluate the developed algorithms by assessing their performance against different scenarios.

8392-18, Session 3

Probability hypothesis density tracking for interacting vehicles in traffic

R. K. Prasanth, H. Hoang, BAE Systems (United States)

The random finite set (RFS) approach to multi-target tracking originating in the work of Mahler has emerged in recent years as a computationally viable alternative to the traditional data association based approaches; see papers on Gaussian mixture based RFS filters by Vo and papers on cardinalized filters by Mahler, Vo, Willett and others. A widely used assumption in the RFS approach for ground moving vehicle tracking is that the vehicles move independently. This assumption is arguably valid for free-driving conditions on freeways and simplifies the tracking problem tremendously. But, it falls apart when interactions among vehicles become strong causing most trackers to fail on real freeway and urban tracking problems. A number of RFS-based group tracking methods have been developed to address this issue of interacting

vehicles; see Septier and Godsill and the references therein for details. In this paper, we introduce the concept of a random finite graph and study its application to the tracking of interacting vehicles. A random finite graph is a random variable taking values in the set of finite directed acyclic graphs (DAGs). It differs from the standard RFS group formulations in the following aspects: (a) the interaction structure of vehicles is modeled by a DAG and its connected components represent groups of interacting vehicles, and (b) the graphical structure of the connected component specifies the joint evolution of the states of vehicles in the group. We illustrate the approach with a realistic two-lane arterial traffic simulation in which vehicles interact among them through car-following and lane-changing, and with traffic control devices at intersections. An airborne wide area imaging sensor emulation is used to generate the measurements. The standard Gaussian mixture RFS filter is used as a baseline to compare performance of the approach based on random finite graphs.

8392-19, Session 3

A comparison of 'clutter-agnostic' PHD/CPHD filters

R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States)

This paper describes a general approach for -PHD/CPHD filters-i.e., PHD/CPHD filters that must estimate the background clutter rate lambda, rather than being provided with it a priori. I first derive general time- and measurement-update equations for lambda-CPHD/PHD filters. I then consider two different Markov motion models. For the Uncoupled Motion (UM) model, targets can transition only to targets, and clutter generators can transition only to clutter generators. For the Coupled Motion (CM) model, targets can transition to clutter generators and vice-versa. I demonstrate that Streit's "intensity filter" (SIF) is actually a lambda-PHD filter with a CM model. Streit has made the following claims for SIF: it subsumes the conventional PHD filter as a special case, and can estimate both lambda and the target-birth rate B. I exhibit counterexamples to these claims: because of the CM model, SIF (1) does not subsume the conventional PHD filter as a special case; (2) cannot estimate B when there are no clutter generators; and (3) cannot estimate lambda when B and the target death-rate r are "conjugate." By way of contrast, lambda-CPHDPHD filters with UM models do include the PHD filter as a special case, as well as estimate lambda. I also show that SIF is essentially identical to the UM-model lambda-PHD filter when B and the target death-rate are both small.

8392-20, Session 4

Spatial voting with data modeling for multiINT fusion and anomaly detection

H. M. Jaenisch, J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We introduce our Spatial Voting with Data Modeling technique for combining MultiINT sources. We show how text information and HUMINT can be combined with geospatial information and imagery to provide an information foot print for behavior recognition and anomaly detection. Our method does not require a priori training. We demonstrate that observation of dynamic behavior and encoding knowledge representations through careful selection of Heptor statistics enables adaptive learning and behavior based tracking with little computational burden. We provide examples and details of how this is accomplished.

8392-21, Session 4

Watercraft detection in cluttered littoral scenes using overcomplete target dictionaries

C. C. Olson, Sotera Defense Solutions, Inc. (United States); J. Nichols, L. B. Smith, K. P. Judd, U.S. Naval Research Lab. (United States)

We present an algorithm for small watercraft detection in a littoral environment characterized by multiple targets and both land- and sea-based clutter. A set of target images is provided as training to a dictionary-learning algorithm. The resulting overcomplete dictionary is then used to decompose sub-sections from a scene of interest with the sparsity of the resulting decomposition indicating the presence or lack of targets. Image segments containing targets are sparsely decomposed while image segments that are poorly represented by the target-specific dictionary (i.e., background) require more dictionary coefficients to reproduce. Thresholding the sparsity of each decomposition allows regions of interest to be selected. Modifications to the algorithm that force given dictionary atoms to be generated from specific target imagery allows for target classification as well as detection. We consider the effect of parameters such as choice of dictionary and segment size on detection performance and present receiver operating characteristic (ROC) curves for short-wave infrared images gathered from a harbor environment.

8392-22, Session 4

Persistent maritime surveillance using multisensor feature association and classification

S. P. van den Broek, P. B. W. Schwering, R. Schleijpen, TNO Defence, Security and Safety (Netherlands)

In maritime scenarios, such as smuggling, piracy, or terrorist threats, it is not only relevant who or what an observed object is, but also where it is now and where it was in the past in relation to other (geographical) objects. In situation and impact assessment, this information is used to determine whether an object is a threat. Single platform (ship, harbour) or single sensor information will not provide all this information. The work presented in this paper focuses on the sensor and object levels, which provide a description of currently observed objects to situation assessment. For use of information of objects at higher information levels, it is necessary to have not only a good description of observed objects at this moment, but also from its past. Therefore, currently observed objects have to be linked to previous occurrences. Kinematic features, as used in tracking, are of limited use, as uncertainties over longer time intervals are so large that no unique associations can be made. Features extracted from different sensors (e.g., ESM, EO/IR) can be used for both association and classification. Features and previous classifications are used to associate current objects to previous object descriptions, allowing objects to be described better, and provide location history.

In this paper first a description of a high level architecture in which such a mutli-sensor association is used is described. Results of an assessment of the usability of several features from ESM ,EO and IR (e.g., shape, keypoints) data for association and classification are shown.

8392-23, Session 4

Target tracking using concurrent visible and infrared imageries

A. L. Chan, U.S. Army Research Lab. (United States); S. R. Schnelle, Rice Univ. (United States)

In typical video surveillance systems, detecting targets of interest and tracking their movements are the most essential functionalities. Due to recent advances in sensor technology and significant reduction in costs, visible and infrared video cameras have become the most widely used imaging sensors for surveillance applications. Furthermore, visible and infrared imageries also exhibit highly complementary target signatures in many operating conditions. Combining the visible and infrared imageries using suitable image fusion methods, especially with the help of indicative contextual information, is therefore expected to produce significantly better detection and tracking performance than relying on visible or infrared imagery separately. On the contrary, some earlier research efforts indicated that many visible-infrared fusion methods could only achieved similar or worse performance in target detection and tracking, as compared to the results obtained by using infrared imagery alone. Nonetheless, we conducted a feasibility study on fusing concurrent visible and infrared imageries using 4 spatial domain and 9 pyramid-based pixel-level fusion algorithms with the aim of improving the tracking performance. The effects of all 13 fusion algorithms on the detection and tracking performance of a given target tracker were analyzed and compared. We found that five of the 9 pyramid-based fusion methods were able to improve the detection and tracking performance across the board, three of which were able to achieve it at a relatively low computational cost as well. The impacts of some contextual or environmental information on the fusion methods and tracking performance are currently investigated.

8392-24, Session 4

Intelligent radiation sensor system

F. R. Facemire, Smiths Detection Edgewood (United States); D. Masi, Smiths Detection (United States); S. Foote, A. Gooden, Intelligent Optical Systems, Inc. (United States); M. Cunningham, Lawrence Livermore National Lab. (United States); J. R. Johnson, Time Domain Corp. (United States)

Homeland security agencies at the Federal, State, Local and Tribal level have deployed radiation detection systems of varied capability for detecting and interdicting rad-nuc threats. These systems are typically operated as stand-alone instruments to perform rad-nuc searches and/or monitoring at points of entry. Under contract with DNDO, our Intelligent Radiation Sensor System (IRSS) team has developed a networked system of portable radiation detection devices that is designed to significantly improve the ability of the overall system to cooperatively detect, localize and identify anomalous rad-nuc sources in areas where checkpoint searches are not feasible. Detector data is communicated through a robust ad hoc wireless data and location awareness network that uses advanced waveforms and signal processing to overcome the attenuation and multi-path fading problems common in urban, shipboard and other RF challenged environments. We fuse this data to reduce the time and false alarms associated with the detection, localization and identification of radiation sources. Situational awareness of the entire system is provided through our FirstView Command and Control console. Key technology features and design constraints of the IRSS system are described.

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8392-25, Session 4

On the probability of detection for a 2D sensor array with correlated measurements

G. Maalouli, Raytheon Missile Systems (United States)

The probability of detection is a key performance metric that assesses a receiver's ability to detect the presence of a signal. Receiver performance is evaluated by comparing empirical measurements against an exact or a bounded theoretical limit. If the detection statistic is based on multiple, independent measurements, it is relatively straight forward to formulate the joint probability density function (PDF) as a multi-variate Gaussian distribution (MVG). In this work, we consider the detection statistic that arises when combining correlated measurements from a two-dimensional array of sensors. The joint PDF does not readily fit into a multi-variate Gaussian model. We illustrate a method by which the correlation matrix for this scenario can be transformed into a block-diagonal, conventional correlation matrix. This matrix is then used to cast the joint PDF in the standard MVG form. This expression can then be evaluated numerically to compute a theoretical probability of detection. We validate the authenticity of the joint PDF using Monte-Carlo simulations.

8392-26, Session 4

Stochastic parsing of GMTI tracker data

B. Balaji, Defence Research and Development Canada, Ottawa (Canada)

Conventional trackers provide the human operator with estimated target tracks. It is desirable to make higher level inference of the target behavior/intent (e.g., trajectory inference) in an automated manner. One such approach is to use stochastic context-free grammars and the Earley-Stoelcke parsing algorithm. The problem of inference is reformulated as one of parsing. In this paper, the robustness of the stochastic parsing of a ground moving target indication (GMTI) tracker data is investigated via simulations. Some conclusions on the required system parameters for acceptable parsing of GMTI tracker data are presented.

8392-27, Session 5

A survey of visual analytics for knowledge discovery and content analysis

A. Shirkhodaie, M. S. Habibi, Tennessee State Univ. (United States)

Abstract: Visual analytics has emerged in past several years for its ability to discover effective knowledge, and is arrived at by integrating data mining with visualization techniques. This survey provides a review of tools and concepts of visual analytics, and the challenges faced by researchers developing application for knowledge discovery. The discovered knowledge is the basis for adaptive situation awareness, as it often provides information beyond the perception of human cognitive mind. A comparison is made based on visualization, analytic features, ability to categorize data, the modeling procedures, interoperability, reliability and portability. Here we explore the issues related to heterogeneous data, its scalability and multi-dimensionality, data fusion, graphical representation, intelligent visualization and user interface by following a two step approach. The first step is the study of current techniques for weighted node link hierarchy representation, cross referencing of data, animated expansion and collapse of meta-data information with primary or secondary visualization. This also includes investigating the environment with the help of data clusters in a dynamic multi-modal sensory network. The next step is the study of intelligent working models capable of performing smart searches in the near and distant past. This paper is an effort to improve upon existing visual analytics models and develop a basis for effective, intelligent and interactive relationship between variables within a data mining process with higher order of certainty and confidence. While visual analytics is hugely important in knowledge discovery, challenges related to computing techniques for avoiding information overload due to inappropriate, irrelevant and uncertain data due to random or fuzzy sensor inputs, also known as noise, are also discussed here. The tools and concepts researched for this article addresses the human computer interaction aspect for intelligent, adaptive decision making from multiple information resources. An attempt is made in this study to combine the strengths of smart search and data analysis, with visual perception and interactive analysis capability of the user.

8392-28, Session 5

A survey on acoustic signature recognition and classification techniques for persistent surveillance systems

A. Shirkhodaie, A. H. Alkilani, Tennessee State Univ. (United States)

Application of acoustic sensors in Persistent Surveillance Systems (PSS) has received considerable attention over the last two decades because they can be rapidly deployed and have low cost. Conventional utilization of acoustic sensors in PSS spans a wide range of applications including: vehicle classification, target tracking, activity understanding, speech recognition, shooter detection, etc. This paper presents a current survey of physics-based acoustic signature classification techniques for outdoor sounds recognition and understanding. Particularly, this paper focuses on taxonomy and ontology of acoustic signatures resulted from group activities. The taxonomy and supportive ontology considered include: human-vehicle, human-objects, and human-human interactions. This paper, in particular, exploits applicability of several spectral analysis techniques as a means to maximize likelihood of correct acoustic source detection, recognition, and discrimination. Spectral analysis techniques based on Fast Fourier Transform, Discrete Wavelet Transform, and Short Time Fourier Transform are considered for extraction of features from acoustic sources. In addition, comprehensive overviews of most current research activities related to scope of this work are presented with their applications. Furthermore, future potential direction of research in this area is discussed for improvement of acoustic signature recognition and classification technology suitable for PSS applications.

8392-29, Session 5

Multimodality sensor data fusion for robust tracking of group activities

V. Elangovan, A. H. Alkilani, A. Shirkhodaie, Tennessee State Univ. (United States)

Recognition and understanding of group activities can significantly improve situational awareness in Persistent Surveillance Systems (PSS). By proper characterization of Human Group Interactions (HGI) certain pertinent threats can be detected and prevented efficiently. In this paper, we present a model-based scheme for robust emergent group activity formation, execution, and dispersion. The proposed approach takes advantage of synergy of multi-sensors to track and identify pertinent individual and group activities. Imagery and acoustic sensors are used for registering new events. Each event has a set of spatiotemporal attributes. By matching and correlating attributes of events, the model attempts to associate sensory observations to known ontology. A modified Hidden Markov Model (HMM) is employed to recognize and classify sequentially occurring events. For each sensor modality a decision is generated. The fusion process combines independent decisions from multi-source sensors to arrive at a final decision describing circumstances of a group activity. To demonstrate the application of this technique, an experimental outdoor group activity consisting of N number of people was conducted. The group activities included loading and unloading of different size objects from a vehicle in an urban environment setting. In this experiment, a surveillance camera, a long-range PTZ camera, and an array of acoustic sensors were used. The surveillance camera was used for detection of whereabouts of humans over a large field of view. Position of target of interest in the surveillance camera image frame was used for guidance of long range PTZ camera. The sound of loading and unloading was used for discrimination of potential objects brought in or taken off from the field site. In this paper, we present the results of our experimental work and demonstrate the effective and robustness of the decision fusion technique in terms of properly classifying group activities and generating semantic messages describing dynamics of human group activities that, in turn, improves situational awareness in PSS.

8392-30, Session 5

Team activity analysis and recognition based on Kinect depth map and optical imagery techniques

V. Elangovan, V. K. Bandaru, A. Shirkhodaie, Tennessee State Univ. (United States)

Kinect cameras produce low-cost depth map video streams applicable for conventional surveillance systems. However, commonly applied image processing techniques are not directly applicable for depth map video processing. Kinect depth map images contain range measurement of objects at expense of having spatial features of objects suppressed. For example, typical objects' attributes such as textures, color tunes, intensity, and other characteristic attributes cannot be fully realized by processing depth map imagery. In this paper, we demonstrate application of Kinect depth map imagery for characterization of indoor and outdoor group activities in complete darkness. A Casual-Events State Modeling (CSM) technique is proposed for spatiotemporal recognition and reasoning of group activities. CSM uses an ontological scheme for representation of casual distinctiveness of a priori known group activities. By tracking and serializing distinctive atomic group activities, CSM allows discovery of more complex group activities. A Modified Sequential Hidden Markov Model (MS-HMM) is implemented for trail analysis of atomic events representing correlated group activities. CSM reasons about five levels of group activities including: Merging, Planning, Cooperation, Coordination, and Dispersion. In this paper, we present results of capability of CSM approach for characterization of group activities taking place both in indoor and outdoor in total darkness. Based on spatiotemporal pattern matching of atomic activities representing a known group activities, the CSM is able to discriminate suspicious group activity from normal activities. This paper presents technical details of imagery techniques implemented for detection, tracking, and characterization of atomic events based on Kinect depth map imagery data sets. Various experimental scenarios carried out in indoors and outdoors (e.g. loading and unloading of objects, human-vehicle interactions etc.,) are presented to demonstrate effectiveness and efficiency of the proposed model in terms of correctly characterization distinctive group activities. Lastly, we have presented a comparison of optical and depth map imagery processing techniques to demonstrate pros and cons of each techniques and fusion opportunity to integrate information from both sensor modalities to further improve situational awareness.

8392-31, Session 5

A goal-driven situation modeling approach for high-level information fusion

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To enable effective situation awareness (SAW), situation modeling is foundational for situation analysis, understanding, and presentation. Typically, SAW is developed from an aggregated assessment of collected data that affords a user a common operating picture (COP). However, the data-driven COP does not utilize a priori knowledge of situation models for efficient decision making. In the proposed work, we develop goal-driven situation models (GdSMs) that enable the situation estimation, filtering, and prediction. Situation modeling elements (SMEs) are defined as objectives, entities, entity attributes, connections and actions, which provide the logic foundation for the SAW framework as well as guidelines for the abstraction of a situation model from real world SAW analysis. High level information fusion (HLIF) functions, e.g., situation modeling, situation estimation and threat analysis are all described using these basic SAW elements. For situation modeling a systematic goal driven (top-down) approach is proposed to correlate sensed data (bottom-up).

It starts from modeling the goals (objectives) of the primary decision maker (DM), who the SAW system is designed to serve, as functions of entity attributes of the DM's interest. Then goal related entities, entity attributes, the underlying connections and other related objectives are accordingly introduced to the situation model. As a result, the situation modeling leads to a network of correlated entity attributes (states) around the objectives of the primary DM and other relevant entities. This goal driven situation modeling approach is able to effectively introduce relevant factors (entities and entity attributes) across different problem domains into the situation model. Using the GSMs, only relevant factors will be introduced, which reduces the modeling complexity. In addition, using the GSM framework facilitates game formulation among multiple DMs to support high level SAW functions such as threat modeling and threat prediction. An example of situation modeling for SAW in a satellite network communication system will be used to demonstrate the effectiveness of the goal-driven proposed situation modeling approach.

8392-32, Session 6

Fundamentals of distributed estimation and tracking

C. Chong, BAE Systems (United States)

No abstract available

8392-33, Session 6

Graphical models for tracking and fusion

C. Chong, BAE Systems (United States)

No abstract available

8392-34, Session 6

Particle filters with Coulomb's Law

F. E. Daum, J. Huang, Raytheon Co. (United States)

We have derived a new nonlinear filter that is similar to Coulomb's law. We show numerical results for a new particle filter that is roughly ten orders of magnitude faster than standard particle filters, and beats the extended Kalman filter by several orders of magnitude in accuracy for difficult nonlinear problems. We use a physics based approach to derive a particle flow that computes Bayes' rule, which moves the particles to the correct region of state space, thereby solving the well known and important problem of particle degeneracy. We derive several new algorithms that are similar to Coulomb's law, including: variance reduction for solving Poisson's equation with meshfree Monte Carlo methods, Tychonoff regularization of same, and direct integration, all of which exploit an exact solution for a related problem. Our numerical results show excellent filter accuracy for diverse problems, including: unstable plants, multimodal densities, variation of signal-to-noise ratio, initial uncertainty of the state vector, dimension of the state vector, process noise, etc. We have solved the well known and important problem of "particle degeneracy" using a new theory, called particle flow. Our filter is four orders of magnitude faster than standard particle filters for any given number of particles, and we required many orders of magnitude fewer particles to achieve the same filter accuracy. Our filter beats the EKF accuracy by several orders of magnitude for difficult nonlinear problems. We show many numerical results for various nonlinearities, with both stable and unstable plants, varying process noise, measurement noise, initial uncertainty of the state vector, and dimension of the plant from d = 1 to 30. Our theory uses exact particle flow to compute Bayes' rule, rather than a pointwise multiply. We do not use resampling or proposal densities or importance sampling or any other MCMC method. But rather, we design the particle flow with the solution of a linear first order highly underdetermined PDE, like the Gauss divergence law in electromagnetics. We study over a dozen methods to solve this PDE, including: (1) irrotational flow (i.e., the gradient of the solution of Poisson's equation); (2) incompressible flow; (3) optimal control; (4) Gauss' and Hertz' variational method; (5) direct integration in terms of d-1 arbitrary functions; (6) complete integrals (i.e., in terms of d arbitrary constants); (7) Fourier transform of the divergence form of our PDE; (8) Gromov's h-principle; (9) generalized inverse of linear differential operator; (10) separation of variables; (11) generalized method of characteristics; (12) generalized Jacobi's method, and hybrids of the above. This talk is for normal engineers who do not have log-homotopy for breakfast.

8392-35, Session 6

Feynman path integral discretization and its applications to nonlinear filtering

B. Balaji, Defence Research and Development Canada, Ottawa (Canada)

In continuous nonlinear filtering theory, we are interested in solving certain parabolic second-order partial differential equations (PDEs), such as the Fokker-Planck equation. The fundamental solution of such PDEs can be written in various ways, such as the Feynman-Kac integral and the Feynman path integral (FPI). In addition, the FPI can be defined in several ways. In this paper, the FPI definition based on discretization is reviewed. This has the advantage of being rigorously defined as limits of finite-dimensional integrals. This is applied to the nonlinear filtering problem with Benes drift, and another derivation of the fundamental solution is obtained.

8392-36, Session 6

Representations of stochastic relations via category theory

M. E. Oxley, Air Force Institute of Technology (United States); J. L. Culbertson, Air Force Research Lab. (United States); K. E. Sturtz, Universal Mathematics (United States)

Learning a situation from data is an on-going current research area. Discovering the relations between entities within a situation may be the most difficult task. Most sensor data is devoted to characterizing the entities, which has issues due to the noise. Also, there are difficulties in combining sensor data from a variety of heterogeneous sources. Using these noisy data sets we seek to generate relations between the entities, thus, the relations will be noisy. We present the mathematics of stochastic relations that provides a framework for the fusion of both hard and soft data at multiple levels of abstraction. We show how this framework can be leveraged to propagate uncertainty throughout the fusion process.

8392-37, Session 6

Feature fusion of detection systems via their ROC functions

M. E. Oxley, J. A. Fitch, C. M. Schubert Kabban, Air Force Institute of Technology (United States)

A detection system outputs two distinct labels - target and non-target. Thus, there are two errors it can make. The Receiver Operating Characteristic (ROC) function quantifies both of these errors as parameters vary within the system. Combining two detection systems typically yields better performance when combination rule is chosen appropriately. When multiple detection systems are fused, the assumption of independence is usually made in order to mathematically combine the individual ROC functions for each system into one ROC function. This paper will investigate feature fusion of multiple detection systems. Given that one knows the ROC function for each individual detection system, we seek a formula with the resultant ROC function of the fused detection systems as a function (specifically, a transformation)

of the respective ROC functions. In this paper we derive this transformation for a certain class of feature rules. Examples will be given that demonstrate how these formulas are used.

8392-38, Session 7

Label fusion of classification systems via their ROC functions

J. A. Fitch, M. E. Oxley, C. M. Schubert Kabban, Air Force Institute of Technology (United States)

A classification system with N possible output labels (or decisions) will have N(N-1) possible errors. The Receiver Operating Characteristic (ROC) manifold was created to quantify all of these errors. When multiple classification systems are fused, the assumption of independence is usually made in order to mathematically combine the individual ROC manifolds for each system into one ROC manifold. This paper will investigate the label fusion (also called decision fusion) of multiple classification systems that have the same number of output labels. Boolean rules do not exist for multiple symbols, thus, we will derive possible Boolean-like rules as well as other rules that will yield label fusion rules. The formula for the resultant ROC manifold of the fused classification systems which incorporates the individual classification systems will be derived. Specifically, given a label rule and two classification systems, the ROC manifold for the fused system is produced. We generate formulas for other non-Boolean-like OR and non-Boolean-like AND rules and give the resultant ROC manifold for the fused system. Examples will be given that demonstrate how each formula is used.

8392-39, Session 7

Immune allied genetic algorithm for structure learning of Bayesian network

Q. Song, F. Lin, Zhejiang Univ. (China); W. Sun, K. Chang, George Mason Univ. (United States)

Bayesian network (BN) structure learning is a NP-hard problem. In this paper, an improved approach to reduce the complexity of BN structure learning is presented. To avoid premature convergence in traditional single-group genetic algorithm (GA), we propose the immune allied genetic algorithm (IAGA) for BN structure learning, in which the multiple-population and allied strategy are introduced. Moreover, we apply prior knowledge in this method by injecting immune operator to individuals which can effectively prevent degeneration. Finally, an experimental simulation is given to illustrate the usefulness of the proposed technique.

8392-40, Session 7

Structure learning of Bayesian network using a chaos hybrid genetic algorithm

J. Shen, F. Lin, Zhejiang Univ. (China); W. Sun, K. Chang, George Mason Univ. (United States)

A new Bayesian network (BN) learning method using a hybrid algorithm and chaos theory is proposed. The principles of mutation and crossover in genetic algorithm and the cloud-based adaptive inertia weight were incorporated into the proposed simple particle swarm optimization (sPSO) algorithm to achieve better diversity, and improve the convergence speed. By means of ergodicity and randomicity of chaos algorithm, the initial network structure population is generated by using chaotic mapping with uniform search under structure constraints. When the algorithm converges to a local minimal, a chaotic searching will be started to skip the local minima and to identify a potentially better network structure. The experiment results reveal that this algorithm can be effectively used for BN structure learning.

8392-42, Session 7

Fundamentals of Dempster-Shafer theory

J. S. J. Peri, The Johns Hopkins Univ. Applied Physics Lab. (United States)

No abstract available

8392-62, Poster Session

Fast diagnosis of emergency situation by telemetry data processing with topological methods

V. F. Dailyudenko, The United Institute of Informatics Problems (Belarus)

Diagnosis of onboard equipment is implemented by means of telemetry data processing with topological nonlinear method, namely the method of temporal localization. Convergence for the function of topological instability at changing dimensionality is attained, and high reliability of diagnosis in a case of emergency caused by failure of equipment unit is proved. The essential reduction of computation time and required experimental data is also attained. Telemetry data are generated from numerical simulations of aerodynamic measurement.

8392-63, Poster Session

Impact point prediction for thrusting projectiles in the presence of wind

T. Yuan, Y. Bar-Shalom, P. Willett, Univ. of Connecticut (United States); D. F. Hardiman, U.S. Army Research, Development and Engineering Command (United States)

To estimate the state of thrusting/ballistic endoatmospheric projectiles for the end purpose of impact point prediction (IPP), the total observation time, the wind effect and the sensor accuracy significantly affect the IPP performance. Based on a multiple interacting multiple model (MIMM) strategy developed in [TY2011], a sensitivity study of the IPP performance with respect to the observation time and measurement accuracy, incorporating the wind effect, are extensively studied.

8392-43, Session 8

Adaptive data reduction with improved information association

V. R. Riasati, MacAulay-Brown, Inc. (United States)

A class of adaptive data compression routines is presented based on the Karhounen-Loeve, KL, transforms. The current class of methods identifies improved information association by utilization of eigen-vectors rather than the eigen-values. The KL transform limits the importance of the data by the limitation of the eigen-values associated with covariance of data, this leads to the truncation of the eigenvectors by their energy levels. Therefore, the remaining data in the KL transform method limits the information that can be represented to those data contents that represent the majority of signal energy as identified by the eigenvalues of the data covariance matrix. The method presented in this work retains desired data structure and enables a representation of the all of the information in the data leading to the preservation of data that can contain significantly relevant information even-though its energy contents may be relatively low and considered insignificant. This work presents a theoretical description of this idea along with an error analysis relative to the original data. The simulation work applies the technique to data from an image by association of neighboring data samples. A discussion of the simulation results though relevant metrics completes the topics considered here.

8392-44, Session 8

Combined use of backscattered and transmitted images in x-ray personnel screening systems

B. H. Tracey, Tufts Univ. (United States); M. Schiefele, American Science and Engineering, Inc. (United States); E. L. Miller, Tufts Univ. (United States); O. Al-Kofani, C. V. Alvino, American Science and Engineering, Inc. (United States)

Current aviation security relies heavily on personnel screening using X-ray backscatter systems or other advanced imaging technologies. Passenger privacy concerns and screening times can be reduced through the use of low-dose two-sided X-ray backscatter (Bx) systems, which also have the ability to collect transmission (Tx) X-ray imagery without increasing the dose. Bx images reveal objects placed on the body, such as contraband and security threats, as well as anatomical features at or close to the surface, such as lungs cavities and bones. While the quality of the transmission images is lower than medical imagery due to the low X-ray dose, Tx images can be of significant value in interpreting features in the Bx images, such as lung cavities. Bx image interpretation and segmentation algorithms can be guided by structures more clearly seen in Tx images. Because of the graphic nature of BX images, automated threat detection (ATR) became necessary to eliminate privacy concerns. We demonstrate an approach that uses automatically extracted fiducial points on the body and localized active contour methods to segment lungs in acquired Tx and Bx images. Additionally, we derive metrics from the Tx image can be related to the probability of observing internal body structure in the Bx image. The combined use of Tx and Bx data can enable improved overall system performance.

8392-45, Session 8

A comparison of Landolt C and triangle resolution targets using the synthetic observer approach to sensor resolution assessment

A. R. Pinkus, D. W. Dommett, Air Force Research Lab. (United States); H. L. Task, Task Consulting (United States)

Resolution is often provided as one of the key parameters addressing the quality capability of a sensor. One traditional approach to determining the resolution of a sensor/display system is to use a resolution target pattern to find the smallest target size for which the critical target element can be “resolved” using the sensor/display system, which usually requires a human in the loop to make the assessment. In previous SPIE papers we reported on a synthetic observer approach to determining the point at which a Landolt C resolution target was resolved; a technique with marginal success when compared to human observers. This paper compares the results of the previously developed synthetic observer approach using a Landolt C with a new synthetic observer approach based on triangle orientation detection (TOD). A large collection of multispectral (visible, near infra-red, and thermal) sensor images of triangle and Landolt C resolution targets were recorded for a wide range of distances. Each image contained both the triangle and the Landolt C resolution targets as well as a person holding a weapon or other object. The images were analyzed using the two different synthetic observer approaches, one for triangles and one for Landolt Cs, and the results compared with each other for the three different sensors. This paper describes the results obtained so far and the planned future effort to compare the results with human visual performance with both the resolution targets and with the hand-held objects.

8392-46, Session 8

Automatic multicamera calibration for deployable positioning systems

M. Axelsson, M. Karlsson, S. Rudner, Swedish Defence Research Agency (Sweden)

Surveillance with automated positioning and tracking of subjects and vehicles in 3D is desired in many defence and security applications. Camera systems with multiple cameras are often used for 3D position estimates. In such systems accurate camera calibration is needed to obtain a reliable 3D position estimate. The camera calibration includes both the intrinsic camera parameters (focal length, principal point, and lens distortion) and extrinsic camera parameters (the relative camera position and orientation).

Automated camera calibration is needed for fast deployment of mobile multi-camera systems. It is desirable to have only a few steps to go trough to set up the system. In this paper we present a technique for automatic calibration of the extrinsic camera parameters of a camera positioning system based on estimation of the essential matrix.
The essential matrix between each camera pair is estimated using corresponding points in the scene obtained from a moving light source. The intrinsic camera parameters of each camera can be calibrated before the system is deployed and is therefore not time critical. The calibration technique is demonstrated and evaluated on data from a field-trial with seven HD cameras which is intended for position subjects in 3D. We compare the automatic calibration technique to a manual calibration technique which requires triangulated physical markers in the scene and manual marking of these in the images. The results show that the automated camera calibration technique provides a result with accuracy which is comparable to the manual calibration of the cameras.

8392-47, Session 8

Extended motion adaptive signal integration technique for real-time image enhancement

D. C. Zhang, SRI International Sarnoff (United States)

Image sensors in fast motion often generate distorted and blurred images characterized by reduced sharpness (due to motion blur) and insufficient dynamic range. To reduce blur often the frame integration time is reduced, but this reduces the intensity of the light captured and thus the image Signal-to-Noise-Ratio (SNR). As our basic Motion Adaptive Signal Integration (MASI) algorithm operates the sensor at a high frame rate, high rate individual image frames are aligned and combined to form an enhanced quality video output in real-time. This technique enables signal integration in the digital domain, allowing both high SNR performance and low motion blur induced by the camera motion. Furthermore, the Extended MASI (EMASI) varies frame-to-frame exposure times via a specific sequence (the “flutter-shutter pattern”) rather than pulses of equal duty cycle. EMASI deblurs the long exposure image by estimating the unit image motion from the short exposure images, and then combines images and finally compress them to form an estimated true image. EMASI broadens the dynamic range of the sensor and extends the sensitivity to work in low light and noisy conditions. In a moving platform, it also reduces static noise in the sensor. This technology can be used in aerial surveillance (especially low flowing UAV’s), satellite imaging, border securities, wearable sensing, video conferencing and cell phone imaging applications.

8392-48, Session 8

Image search engine development

P. L. Cho, M. Yee, MIT Lincoln Lab. (United States)

Billions of photos may now be accessed via web archives. Yet navigating through image repositories generally requires clicking through a sea of thumbnails. Aside from occasional keywords, little connection typically

exists between thumbnails to help users find images of interest. Better search capabilities are consequently needed to mine huge digital imagery volumes.

In this talk, we present a set of software tools that enable user exploration of global structure and individual picture drill-down. Our tools build upon recent computer science advances. We review these algorithmic developments working with a set of 30K+ photos shot around MIT in July 2009.

We subsequently describe our search engine's netcentric design that allows for multi-user collaboration. Our system's front-end provides a graph viewer thick client and web browser thin client whose states remain automatically synchronized. Hierarchical clustering generates pyramid structures for a priori unorganized sets of input images. Perusing higher, sparser levels in an image pyramid provides a practical way to gain comprehensive looks into large picture collections.

We next demonstrate our search engine's utility for organizing random internet images on a set of 15K ground photos of the Grand Canyon. After these uncooperatively-gathered ground stills are combined with aerial video frames purposefully shot over the Grand Canyon, we discover a weak link between the two disparate data sets. This example illustrates the tantalizing possibility of matching other aerial video images with tactically interesting ground views.

We close with future DoD applications of this work that include intelligence propagation, photo geolocation and anomaly nomination.

8392-49, Session 9

Adaptive optics to enhance target recognition

A. D. McAulay, Lehigh Univ. (United States)

Target recognition can be enhanced by reducing image degradation due to atmospheric turbulence and by lidar (light detection and ranging) to provide precise distance to parts of the target. Both of these enhancements may be accomplished by adaptive optic systems and the results can be fused together during target recognition. We discuss the forms of degradation when a target is viewed through the atmosphere [1]: shimmering of ground targets on a hot day in visible or infrared light; beam spreading and wavering around in time; atmospheric turbulence caused by motion of the target or by weather. In the case of targets we can use a beacon laser that reflects back from the target into a wavefront detector to measure the effects of turbulence on propagation to and from the target [1]. A deformable mirror then corrects the transmitted, reflected or scattered data for enhanced imaging. Further, recognition of targets is enhanced by performing accurate distance measurements to localized parts of the target using lidar which sends a short pulse to localized parts of the target and measures the times for each pulse to return from each reflector in that part. There is inadequate time to scan the complete field of view so that the beam must be steered to regions of interest such as extremities of the image during image recognition. Distance is particularly valuable when segmentation is required to separate a target from background or from other targets or to recognize fine features in range along the target. We discuss the issues involved.

[1] A. D. McAulay, A., D., Military Laser Technologies for Defense, Wiley, New York, (2011).

8392-50, Session 9

Detection, classification, and tracking of compact objects in video imagery

M. J. Carlotto, General Dynamics Advanced Information Systems (United States)

A video data conditioner (VDC) for automated full-motion video (FMV) detection, classification, and tracking is described. VDC extends our multi-stage IMINT data conditioner (IDC) to video. Key features includes robust detection of compact objects in pan/EO motion imagery, coarse classification of all detections, and tracking of fixed and moving objects. An implementation of the detection and tracking components of the VDC on an Apple iPhone is discussed. Preliminary tracking results of naval ships captured during the Phoenix Express 2009 Photo Exercise are presented.

8392-51, Session 9

Adaptive polarimetric change detection and interpretation based on supervised ground-cover classification using SAR and optical imagery

M. Ghazel, J. Busler, V. Kotamraju, MacDonald, Dettwiler and Associates Ltd. (Canada); G. Aubé, Canadian Space Agency (Canada); C. Froese, Alberta Geological Survey (Canada)

This paper describes a semi-automated polarimetric change detection and interpretation methodology based on supervised ground cover classification using concurrent SAR and optical satellite imagery. In general, detected polarimetric changes which are mainly attributed to a single dominant backscatter can be classified with a high degree of confidence. However, when the detected changes are attributed to a mixture of different types of scattering, it is more difficult to identify their likely sources. A change detection classification method has been developed to perform a supervised classification of ground cover of the input RADARSAT-2 polarimetric images using training regions identified from high resolution, multi-spectral optical imagery. The class statistics of the training set are computed using SAR imagery acquired at the same time period as the optical imagery. The detected changes are classified based on the change of the ground cover from one image to another. The proposed ground cover classification method allows the production of adaptive, context-based change detection, where different change detection algorithms or input parameters may be used for different types of ground cover. In this paper, we shall present and validate classified change detection products generated from repeat-pass RADARSAT-2 polarimetric data using the proposed methodology which highlight agricultural and structural changes of interest and mask other changes.

8392-52, Session 9

A novel algorithm for multimodal scene-matching, image registration, and object matching

R. Seely, S. Page, Waterfall Solutions Ltd. (United Kingdom)

This paper presents a high performance feature matching algorithm which can be used for multi-modal scene-matching, wide baseline image registration, and object matching. The algorithm works by identifying and matching coarse-level features in the reference and input imagery. In contrast to many existing approaches, the algorithm is not waveband specific and can be used to reliably match and register multi-modal imagery. In addition the algorithm exploits efficient integral image decompositions, and simple yet robust feature descriptors, rendering it amenable to real-time implementation on a variety of hardware platforms. Example results of applying the algorithm to the registration and matching of visible-band and LWIR imagery with large camera separations and rotation and scale variations are presented. The algorithm has been implemented in real-time on a low-power embedded hardware platform at a frame-rate of 50Hz. In addition to global image-level matching and registration, the algorithm can also be used to match objects in imagery against pre-defined object shape models. The matching output can be used readily as the input to an object tracking process. In addition to the rotation and scale-invariance properties derived from the used of the scene-matching and registration process, the object matching process is capable of handling minor object-shape variation. This variation of the algorithm has been implemented in real-time using a low-power embedded PC platform

8392-53, Session 9

Near real-time face detection and recognition using a wireless camera network

F. Nicolo, S. Parupati, V. Kulathumani, N. A. Schmid, West Virginia Univ. (United States)

We present a portable wireless multi-camera network based system that quickly recognizes face of human subjects. The system uses low-power embedded cameras to acquire video frames of subjects in an uncontrolled environment and opportunistically extracts frontal face images in real time. The extracted images may have heavy motion blur, small resolution and large pose variability. A quality based selection process is first employed to discard some of the images that are not suitable for recognition. Then, the face images are geometrically normalized according to a pool of four standard resolutions, by using coordinates of detected eyes. The images are transmitted to a fusion center which has a multi-resolution templates gallery set. An optimized double-stage recognition algorithm based on Gabor filters and simplified Weber local descriptor is implemented to extract features from normalized probe face images. At the fusion center the comparison between gallery images and probe images acquired by a wireless network of seven embedded cameras is performed. A score fusion strategy is adopted to produce a single matching score. The performance of the proposed algorithm is compared to the commercial face recognition engine Faceit G8 by L1 and other well known methods based on local descriptors. The experiments show that the overall system is able to provide similar or better recognition performance than the commercial engine with a shorter computational time, especially with low resolution face images. In conclusion, the designed system is able to detect and recognize individuals in near real time.

8392-54, Session 9

Target tracking and surveillance by fusing stereo and RFID information

R. H. Raza, G. C. Stockman, Michigan State Univ. (United States)

Ensuring security in high risk areas such as an airport is an important but complex problem. Effectively tracking personnel, containers, and machines is a crucial task. Moreover, security and safety require understanding the interaction of persons and objects. Computer vision (CV) has been a classic tool; however, variable lighting, imaging, and random occlusions present difficulties for real-time surveillance, resulting in erroneous object detection and trajectories. Determining object ID via CV at any instance of time in a crowded area is computationally prohibitive, yet the trajectories of personnel and objects should be known in real time. RFID can be used to reliably identify target objects and can even locate targets at coarse spatial resolution, while CV provides fuzzy features for target ID at finer resolution. Our research demonstrates benefits obtained when most objects are “cooperative” by being RFID tagged. Fusion provides a method to simplify the correspondence problem in 3D space. A surveillance system can query for unique object ID as well as tag ID information, such as target height, texture, shape and color, which can greatly enhance scene analysis. We extend geometry-based tracking so that intermittent information on ID and location can be used in determining a set of trajectories of N targets over T time steps. We show that partial-target-information obtained through RFID can reduce computation time (by 99.9% in some cases) and also increase the likelihood of producing correct trajectories. We conclude that real-time decision-making should be possible if the surveillance system can integrate information effectively between the sensor level and activity understanding level.

8392-55, Session 10

Challenge problem for ladar recognition confidence

A. R. Nolan, Etegent Technologies, Ltd. (United States)

In this paper we present a target recognition challenge problem sponsored by the Automatic Target Recognition Theory Center. The goal of this challenge problem is to leverage knowledge of the operating conditions to define an estimate of the inference posterior (recognition confidence). This paper will outline data sets, relevant operating conditions, and evaluation criteria. This challenge problem has been defined for two distinct sensor modalities, LADAR and RADAR. The evaluation of algorithm performance will include 3 key components 1) probability of correct identification, 2) estimates of the inference posterior derived strictly from operating conditions, and 3) estimates of the inference posterior which combine observed signatures with known operating conditions.

8392-56, Session 10

Morphological detectors for radar ELINT applications

J. Rivest, S. Rajan, Defence Research and Development Canada, Ottawa (Canada)

Assessment of threat in a battlefield environment depends heavily on quick and appropriate analyses of Electronic Intelligence (ELINT) signals. Most of the ELINT signals may be hard-to-detect, non-persistent and may have advanced modulations. This dictates the need for advanced signal processing techniques that can simultaneously handle nonstationarities and provide processing gain to enable a reliable detection. Short-time Frequency transforms (STFT) are frequently used as a fundamental step of signal processing in Electronic Warfare (EW) to obtain the distribution of energy in the two dimensional time-frequency plane. STFT may be viewed as a representation achieved through simultaneous frequency and time translations on a plane. Translation-invariant operators such as STFTs provide intelligence through signal detection and characterization based on the signal’s evolution in time and frequency. Moreover, under the right conditions, weak signals can be detected more readily than by using the usual wide-band signal detectors. Since these STFTs are 2-D objects similar to images, it is attractive to apply image processing techniques on them. This paper aims to present a STFT-based morphological detection approach for ELINT. Although morphological signal processing has been used for radar ELINT signals, there has no contribution in the open literature on viewing morphological operations as a detection process. In this paper, detectors obtained through morphological processing such as double threshold, top hat, regional maxima and watershed are considered. The pros and cons of using detectors based on such processing techniques are discussed. Suitability of such detectors for low power, low probability of intercept (LPI) radar signals is illustrated. The contribution by this study is relevant and is significant due to the proliferation of LPI radars and the introduction of inexpensive high performance DSP capabilities in radar designs.

8392-57, Session 10

Support vector machines classification using direct eigenvector data reduction

V. R. Riasati, MacAulay-Brown, Inc. (United States)

Principal Component Analysis (PCA) has been used in a variety of applications like feature extraction for classification, data compression and dimensionality reduction. Often, a small set of principal components are sufficient to capture the largest variances in the data. As a result, the eigen-values of the data covariance matrix with the lowest magnitude are ignored (along with their corresponding eigen-vectors) and the remaining eigen-vectors are used for representation. It is well known that this process of choosing a few principal components naturally causes a loss in information from a signal reconstruction standpoint. We propose a new technique by modifying the PCA to represent the data in terms of a new set of basis vectors where the high-frequency detail is preserved. Instead of thresholding the eigen-values, we retain all eigen-values, instead applying thresholds on the components of each eigen-vector separately. The resulting basis vectors can no longer be interpreted as eigen-vectors and do not exhibit orthogonality, but offer benefits in terms of preserving detail that is crucial for classification tasks. We test the merits of this new basis representation for synthetic aperture radar (SAR) Automatic Target Recognition (ATR). A feature vector is obtained by projecting a SAR image onto the aforementioned basis. Decision engines such as support vector machines (SVMs) are trained on example feature vectors per class and ultimately used to recognize the target class in real-time. Experimental validation will be performed on the MSTAR database and will involve comparisons against traditional PCA based ATR algorithms.

8392-58, Session 10

Detection of unusual trajectories using classificatory decomposition

T. G. Smolinski, T. Newell, S. McDaniel, D. Pokrajac, Delaware State Univ. (United States)

Detection of unusual trajectories of moving objects (e.g., people, automobiles, etc.) is an important problem in many surveillance applications. The problem can be considered a two-class classification/prediction task: given a set of characteristic trajectories, can we build a classifier capable of recognizing typical, but yet unseen, trajectories, and identifying unusual ones? Classificatory decomposition (CD) is a signal decomposition technique that breaks down the original signals (e.g., 2- or 3-dimensional trajectories) into a set of additive components. However, instead of assuming orthogonality (as in Principal Component Analysis) or statistical independence (as in Independent Component Analysis) in the process of decomposition, the algorithm attempts to extract a small number of components (also called basis functions) that are most useful for the underlying classification problem. The main assumption in CD is that the basis functions are relatively constant for all of the observable signals (e.g., various aspects of movement across a scene), but are expressed differently due to some underlying classification scheme (e.g., typical vs. unusual trajectory). The variation of expression of the basis functions between different classes is characterized by the differences in the coefficients. Therefore, by computing coefficients for a novel trajectory in the space spanned by the basis functions generated from the training set, and matching them against a simple classifier, we can determine if said trajectory is typical, or if, perhaps, a target-acquisition procedure should be launched. We evaluate this approach on ground truth trajectories extracted from the SENSIAC database and from surveillance videos generated at Delaware State University.

8392-60, Session 10

Detection of slow-moving targets in sea clutter by HRR generalized detector

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

The radar detection of targets in the presence of sea clutter has relied upon the radial velocity of targets with respect to the radar platform either by exploiting the relative target Dopplers (for targets with sufficient radial velocity) or by discerning the paths targets traverse from scan to scan. For targets with little to no rapid velocity component, though, it can become quite difficult to differentiate targets from the surrounding sea clutter. The present paper addresses the detection of slow-moving targets in sea clutter using the high resolution radar (HRR) based on the generalized detector (GD) constructed in accordance with the generalized approach to signal processing (GASP) in noise such that the target has perceptible extent in range. Under the assumption of completely random sea clutter spikes based on an -contaminated mixture model with the signal and clutter powers known, the best detection performance results from using the GD and is compared with that of the generalized likelihood ratio test (GLRT). For realistic sea clutter, the clutter spikes tend to be a localized phenomenon. Based upon observations from real radar data measurements, a heuristic approach exploiting a salient aspect of the idealized GD is developed which is shown to perform

8392-61, Session 10

Fast methods for fusing visible/IR images and colorizing IR image with natural color appearance under sea-sky scene

L. Wang, R. Chen, B. Zhang, Y. Gao, Beijing Institute of Technology (China)

Color transfer is an effective way to render black and white visible and infrared images (called source image) with natural color appearance according to the brightness and color distribution of a day-time color visible image (called reference image). The rendered results rely heavily on the reference image. But till now, no quantified method is proposed to select a most optimal reference image for source images with different contents. At the same time, researchers have developed various methods to accurately transfer color from the reference image to the source image, such as local transfer based on image segmentation, non-linear transfer based on hot target enhancement. However, we are aiming at simplifying the complicated computation. Firstly, a large amount of reference images are categorized as several typical scenes: sea-sky scene, land-plant-sky scene, desert-sky scene, and snow-sky scene. Secondly, fast computation algorithms are developed to obtain robust color appearances rather than very accurately transferred results under different typical scenes. In this paper, fast methods for fusing visible/IR images and colorizing IR image with natural color appearance under sea-sky scene are mainly presented. Subjective observing experiments are conducted to determine that rendering hot targets in IR image white pink will obtain good contrast with blue sea and sky. Then the three channels of YUV color space have been modulated by the grey value of hot targets. Field test results showed that this method is robust for fusing sea-sky visible and IR images which contain different targets, such as building, boat, bridge or human. In addition, this method is modified to colorize single band sea-sky IR image and still obtain good color appearance.

SPIE Defense, Security+Sensing

8393-01, Session 1

Muzzle flash detection using thermoelectrically cooled linear arrays

M. C. Ertem, R. B. Pierson, E. Heidhausen, B. A. Besse, T. Pierce, Univ. Research Foundation (United States); J. Kane, Computer Optics, Inc. (United States)

Two prototype units were built using thermoelectrically cooled PbSe arrays, with several lens configurations - spherical and anamorphic. These were tested against various small caliber weapons, from stationary and moving platforms, and at ranges greater than the effective range of the weapons used. It was found that among temporal, spatial, spectral and morphological filters that can be used to discriminate gunflash, the temporal flash filter was the best discriminator of gunflash. Sacrificing one spatial dimension (typically elevation) for greater temporal resolution allowed improved detection range, while false alarms were almost eliminated. The field test results indicate that a thermoelectrically cooled linear array based system - which would be at a fraction of the cost of a cooled FPA system - would be a better solution. The paper describes the design of the system, the algorithms used, the optics developed, and performance in the field.

8393-02, Session 1

Detecting clustered chemical/biological signals in noisy sensor feeds using adaptive fusion

S. Lundberg, Numerica Corp. (United States)

Chemical and biological monitoring systems are faced with the challenge of detecting weak signals from contaminates of interest while at the same time maintaining extremely low false alarm rates. We present methods designed to help control the number of false alarms while maintaining strong power to detect. Threats are modeled as clustered signals produced from underlying sensor specific detection algorithms. By learning from past data, an adaptive background model is constructed that is used to control the false alarm rate through multi-hypothesis testing methods.

Detection methods for Chem/Bio releases often depend on specific models for release types and sensor missed detection rates. This can be problematic in field situations where environment specific effects can alter both a sensor's false alarm and missed detection characteristics. The false alarm statistics of a given sensor can be adaptively learned from live field data and used for inference; however the missed detection statistics for a sensor are not well observable while in the field. As a result, we pursue methods than do not rely on accurate estimates of a sensor's missed detection rate. The algorithms presented are, under restrictive assumptions, designed to conservatively control the expected rate of false alarms. These assumptions are then relaxed and the methods are applied to more general detection problems encompassing realistic data.

8393-03, Session 1

Variable basis function least squares for chemical classification of surface enhanced Raman spectroscopy (SERS) data

D. K. Emge, U.S. Army Edgewood Chemical Biological Ctr. (United States); S. Kay, The Univ. of Rhode Island (United States)

The ability to detect and identify trace chemical, explosive, and biological materials is a highly sought after capability. One technique that offers great promise to address these problems is the use of surface enhanced Raman spectroscopy (SERS). Raman spectroscopy, on which SERS is based, offers a highly selective method to identify materials based upon their unique spectral fingerprint. SERS offers a significant enhancement, reported on the order of 106, over normal the normal Raman signal response. One difficulty, however, in utilizing SERS full capabilities is that the spectrum is highly dependent upon the chemical concentration and geometric orientation of the SERS particles. Spectral peaks can shift and even disappear as a function of concentration. A potential solution to this problem is to model the spectrum as a set of random basis functions, with each basis function depending upon a random unobserved parameter. Relating these parameters to the concentration an expected least squares fitting procedure can be implemented. It is shown through computer simulation and some limited testing that the detection and classification performance can be improved over standard approaches that do not take into account these basis variation. The method proposed, however, is completely general. It is a viable alternative to standard least squares procedures whenever the goal is robustness of the procedure.

8393-04, Session 1

Investigation of kinematic features for dismount detection and tracking

R. Narayanaswami, A. Tyurina, D. Diel, R. K. Mehra, Scientific Systems Co., Inc. (United States); J. Chinn, Air Force Research Lab. (United States)

With recent changes in threats and methods of warfighting and the use of unmanned aircrafts, ISR (Intelligence, Surveillance and Reconnaissance) activities have become critical to the military's efforts to maintain situational awareness and neutralize the enemy's activities. The identification and tracking of dismounts from surveillance video is an important step in this direction. Our approach combines advanced ultra fast registration techniques to identify moving objects with a classification algorithm based on both static and kinematic features of the objects. Our objective was to push the acceptable resolution beyond the capability of industry standard feature extraction methods such as SIFT (Scale Invariant Feature Transform) based features and inspired by it, SURF (Speeded-Up Robust Feature). Both of these methods utilize single frame images. We exploited the temporal component of the video signal to develop kinematic features. Of particular interest were the easily distinguishable frequencies characteristic of bipedal human versus quadrupedal animal motion. We examine limits of performance, frame rates and resolution required for human, animal and vehicles discrimination. A few seconds of video signal with the acceptable frame rate allow us to lower resolution requirements for individual frames as much as by a factor of five, which translates into the corresponding increase of the acceptable standoff distance between the sensor and the object of interest.

8393-05, Session 1

VNIR data processing of small (human) targets

D. S. Rosario, U.S. Army Research Lab. (United States)

We demonstrate that human skin biometrics in the visible to near infrared (VNIR) regime can be used as reliable features in a multistage human target tracking algorithm suite. We collected outdoor VNIR hyperspectral data of human skin, consisting of two human subjects of different skin types in the Fitzpatrick Scale (Type I [Very Fair] and Type

III [White to Olive]), standing side by side at seven ranges (50 ft to 370 ft) in a suburban background. At some of these ranges, the subjects fall under the small target category. We developed a three-step approach consisting of: Step 1 - reflectance retrieval; Step 2 - exploitation of absorption wavelength line at 577 nanometers, due to oxygenated hemoglobin in blood near the surface of skin; and Step 3 - large-sample hypothesis test based on two reduced statistics and a novel sampling scheme designed to augment the sample size of small scale objects in the scene. Step-3 functionality is only applied to regions in the imagery showing evidence of human skin, as determined by Step 2. The approach produced excellent results tracking the presence of human skin in the example dataset, yielding zero false alarms from potential confusers in the scene, and regardless of the target's kinematic state. The approach will function as the focus of attention stage of a multistage algorithm being currently developed, where an initial spectral sample of a human target (e.g., hat, shirt, pants) will be used for tracking the target in the vicinity of human skin in subsequent frames.

8393-06, Session 1

Multichannel adaptive generalized detector based on parametric Rao test

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

The parametric Rao test for multichannel adaptive signal detection by the adaptive generalized detector (AGD) constructed based on the generalized approach to signal processing in noise is derived by modeling the disturbance signal as a multichannel autoregressive process. The parametric Rao test takes a form identical to that of parametric AGD for space-time adaptive processing in airborne surveillance radar systems and other similar applications. The equivalence offers new insights into the performance and implementation of the AGD. Specifically, the Rao/AGD is asymptotically (in the case of large samples) a parametric generalized likelihood ratio test (GLRT) due to an asymptotic equivalence between the Rao test and the GLRT. The asymptotic distribution of the Rao/AGD test statistic is obtained in closed form, which follows an exponential distribution under the null hypothesis (the target return signal is absent) and, respectively, a noncentral Chi-squared distribution with two degrees of freedom under the alternative hypothesis (the target return signal is present). The noncentrality parameter of the noncentral Chi-squared distribution is determined by the output signal-to-interference-plus-noise ratio of a temporal whitening filter. Since the asymptotic distribution under the null hypothesis is independent of the unknown parameters, the Rao/AGD asymptotically achieves constant false alarm rate (CFAR). Numerical results show that these results are superior in predicting the performance of the parametric adaptive matched filter detector even with moderate data support.

8393-08, Session 2

Space-time signal processing for distributed pattern detection in sensor networks

R. C. Paffenroth, P. C. Du Toit, Numerica Corp. (United States); L. L. Scharf, A. P. Jayasumana, V. Banadara, Colorado State Univ. (United States)

We describe a mathematical and computational framework for detecting and classifying weak, distributed patterns in sensor networks. Our work demonstrates the effectiveness of space-time inference on graphs, robust matrix completion, and second order analysis in the detection of distributed patterns that are not discernible at the level of individual nodes. The resulting capabilities are applicable to many types of sensor networks including computer networks, databases, wireless networks, mobile sensor networks, social networks, and disease outbreaks. Motivated by the importance of the problem, we are specifically interested in detecting weak patterns in computer networks related to Cyber Situational Awareness. Our focus is on scenarios where the computer nodes (terminals, routers, servers, etc.) are sensors that provide measurements (of packet rates, user activity, CPU usage, etc.) that, when viewed independently, cannot provide a definitive determination of the underlying pattern, but when fused with data from across the network both spatially and temporally, the relevant patterns emerge. The clear underlying suggestion is that only detectors and classifiers that use a rigorous mathematical analysis of temporal measurements at many spatially-distributed points in the network can identify network attacks.

8393-09, Session 2

Physics and particle filters

F. E. Daum, J. Huang, Raytheon Co. (United States)

We show numerical results for a new particle filter that is roughly ten orders of magnitude faster than standard particle filters, and beats the extended Kalman filter by several orders of magnitude in accuracy for difficult nonlinear problems. We use a physics based approach to derive a particle flow that computes Bayes' rule, which moves the particles to the correct region of state space, thereby solving the well known and important problem of particle degeneracy. We derive several new algorithms, including: variance reduction for solving Poisson's equation with meshfree Monte Carlo methods, Tychonoff regularization of same, and direct integration, all of which exploit an exact solution for a related problem. Our numerical results show excellent filter accuracy for diverse problems, including: stable and unstable plants, multimodal densities, highly nonlinear dynamics and measurement equations, variation of signal-to-noise ratio, initial uncertainty of the state vector (varied by orders of magnitude), dimension of the state vector (d = 3 to 30), process noise (varied by orders of magnitude), etc. We use several ideas and algorithms borrowed from physics to derive our filter; in particular, one of our algorithms is similar to Coulomb's law in electromagnetism, and the resulting flow of particles is similar to a plasma in d-dimensions. Our fundamental PDE is similar to the Gauss divergence law in electromagnetism, with a charge density deduced from the likelihood and conditional density; the necessary & sufficient condition for the existence of a solution to this PDE is that the charge density is exactly zero averaged over the relevant volume in state space. It turns out that ideas from plasma physics are crucial to make the filter work robustly.

8393-10, Session 2

Conference overview

O. E. Drummond, Consultant (United States)

No abstract available

8393-11, Session 2

Lagrangian relaxation approaches to closed-loop scheduling of track updates

K. A. B. White, J. L. Williams, Defence Science and Technology Organisation (Australia)

Many modern agile sensor systems are capable of being adaptively tasked in response to an evolving environment. This paper describes experiments with an algorithm developed in the framework of previous work by Castanon, and Wintenby and Krishnamurthy. The goal is to schedule the time and dwell time for updates of targets under track using a phased array radar. This problem is addressed using Lagrangian relaxation, decoupling the joint optimisation into a series of single target problems. After discretising the single target decision state (i.e., the covariance matrix), these single target problems are easily solved as Markov decision processes. Experiments are performed with different methods for selecting the state space discretisation.

8393-12, Session 2

Extrapolating target tracks

J. R. Van Zandt, The MITRE Corp. (United States)

Steady-state performance of a tracking filter is traditionally evaluated immediately after a track update. However, there is commonly a further delay (e.g., processing and communications latency) before the tracks can actually be used. We analyze the accuracy of extrapolated target tracks for four tracking filters:

Kalman filter with the Singer maneuver model and worst-case correlation time, with piecewise constant white acceleration, and with continuous white acceleration, and the reduced state filter proposed by Mookerjee and Reifler.

Performance evaluation of a tracking filter is significantly simplified by appropriate normalization. For the Kalman filter with the Singer maneuver model, the steady-state RMS error immediately after an update depends on only two dimensionless parameters. By assuming a worst case value of target acceleration correlation time, we reduce this to a single parameter without significantly changing the filter performance (within a few percent for air tracking).

With this simplification, we find for all four filters that the RMS errors for the extrapolated state are functions of only two dimensionless parameters. We provide simple analytic approximations in each case.

8393-13, Session 2

The study on infrared small target tracking technology under complex background

L. Liu, Nanjing Univ. of Science & Technology (China); X. Wang, Hohai Univ. (China); J. Chen, T. Pan, Nanjing Univ. of Science & Technology (China)

Small target tracking in infrared (IR) image sequences has been an important part in many military or civil fields such as video supervision, precision guidance and human-computer interfaces. Nowadays, different algorithms have been proposed for infrared target tracking. However, under complex backgrounds, such as clutter, varying illumination, and occlusion, the traditional tracking method often loses the real infrared small target. To cope with these problems, in this paper we have researched on the traditional infrared small target tracking methods, summarized the advantages and disadvantages of these algorithms. On the basis of the analysis of these methods, according to the characteristics of the small target in infrared images, we propose an improved tracking algorithm to enhance the tracking performance. The experimental results show that, compared with the traditional algorithm, the presented method greatly improves the accuracy and effectiveness of infrared target tracking under complex scenes, and the results are satisfactory.

8393-28, Session 2

A mathematical model for MIMO signal and SAR image

A. Martinez, Y. Cao, Z. Qiao, The Univ. of Texas-Pan American (United States)

Multiple Input Multiple Output- MIMO Radar is a fast growing research area. This poster will give a brief introduction to the subject, as well as provide simulated interference patterns for different antenna layouts using Matlab. The general problem of radar imaging is to use some physical model for a transmitted signal, and measurements of the signal that is scattered back to a reciever by a scene to attempt and derive information about the scene. The concept of communication involves a message sender, a message reciever, and a channel. The sender sends a message through the channel to the reciever. The reciever attempts to recover the original message. . MIMO communication is just communication that involves sending several messages to several recipients. The problem of Multiple Input Multiple Output Radar Imaging is to use the corruption of transmitted messages to try and derive useful information about the environment that the messages traveled through. The extra information gained with MIMO Radar can be used to get rid of false targets, detect moving targets, and create a better resolution image. The plan for this research is to culminate to an in-scene 3-d Image reconstruction algorithm. The model presented provides a context in which to examine this problem

8393-15, Session 3

The PMHT for fused tracking

D. T. Dunham, Vectraxx, Inc. (United States); P. Willett, Univ. of Connecticut (United States); T. Ogle, Vectraxx, Inc. (United States)

Fusing data together for target tracking is a complex problem. There are two key steps. First, the raw observations must be associated with existing tracks or used to form new tracks. Once the association has been done, then the tracks can be updated and filtered with the new data. The updating and filtering is usually the easier of the two parts and it is the association that can lead to most of the complexity in target tracking. When associating data (either measurements or tracks or both) with existing tracks, the separation between the tracks is critical to how difficult the association decisions will be. If the tracks are widely separated then the association decisions can be relatively easy. On the other hand, when the tracks are closely spaced the association decisions can be very difficult or nearly impossible. When the tracks or measurements are in three dimensions (such as with active sensors) the association can be accomplished in all three dimension thus making an easier distinction of targets that may be very close in two dimensions, but distant in the third dimension. However, when there are only two dimensions (as for passive sensors) observed by a sensor, targets that are widely separated may appear to be very close or even unresolved. In this paper, we will discuss the issues involved with applying the Probabilistic Multi-Hypothesis Tracking (PMHT) algorithm to a distributed tracking problem where there are passive sensors.

8393-16, Session 3

Ambiguous data association and entangled attribute estimation

D. J. Trawick, P. C. Du Toit, R. C. Paffenroth, G. J. Norgard, Numerica Corp. (United States)

This paper presents an approach to attribute estimation based on data association ambiguity. In modern tracking systems, time pressures often leave all but the most likely data association alternatives unexplored, possibly producing track inaccuracies. Numerica's Bayesian Network Tracking Database, a key part of its Tracker Adjunct Processor, captures and manages the data association ambiguity for further analysis and possible reduction/resolution using subsequent data.

Attributes are non-kinematic discrete sample space sensor data and they may be as distinctive as aircraft ID, or as broad as friend or foe. Attribute data may provide improvements to data association by a process known as Attribute Aided Tracking (AAT). Indeed, certain uniquely identifying attributes (e.g. aircraft ID), when continually reported, can be used to define data association (tracks are observations with the same ID). However, attribute data arriving infrequently, combined with unambiguous data associations in error, can produce incorrect attribute and kinematic state estimation.

Ambiguous data associations define the tracks that are entangled with each other. Attribute data observed on an entangled track then modify the attribute estimates on all entangled tracks. For example, if a red track and a blue track pass through a region of data association ambiguity, these tracks become entangled. Later red observations on one entangled track make the other track more blue, and reduce the data association ambiguity. Methods for this analysis have been derived and implemented for efficient forward filtering and forensic analysis.

8393-17, Session 3

Measurement level AIS/radar fusion for multitarget tracking

B. K. Habtemariam, R. Tharmarasa, McMaster Univ. (Canada); E. Meger, exactEarth Ltd. (Canada); T. Kirubarajan, Mcmaster Univ. (Canada)

Using the Automatic Identification System (AIS) ships identify themselves intermittently by broadcasting their location information. However, traditionally radars are used as the primary source of surveillance and AIS is considered as a supplement with a little interaction between these data sets. The data from AIS is much more accurate than radar data with practically no false alarms. But unlike the radar data, the AIS measurements arrive unpredictably, depending on the type and behavior of ships.

The AIS data includes target IDs that can be used to associate or fuse with the tracks initialized based on the radar measurements. In multitarget maritime surveillance environments, for some targets the revisit interval form the AIS could be very large (e.g., 30 min or 1 hour). In addition, the revisit intervals for various targets are different, which makes measurement-to-track association and filtering challenging. In this work, we propose a multiframe assignment based tracking algorithm that addresses the aforementioned issues to fuse the radar measurements with AIS while improving the overall target state estimation accuracy. Experimental results based on simulated data demonstrate the performance the proposed technique.

8393-18, Session 3

Maximum likelihood probabilistic data association (ML-PDA) tracker implemented in delay-dime/bearing space applied to multistatic sonar data sets

S. Schoenecker, Naval Undersea Warfare Ctr. (United States); P. Willett, Y. Bar-Shalom, Univ. of Connecticut (United States)

The Maximum Likelihood Probabilistic Data Association (ML-PDA) tracker is an algorithm that has been shown to work well against low-SNR targets in an active multistatic framework with multiple transmitters and multiple receivers. In this framework, measurements are usually received in delay-time/bearing space. Prior work on ML-PDA implemented the algorithm in Cartesian state-space - this involved converting the measurements and their associated covariances to Cartesian space. The assumption was made that Gaussian measurement error distributions in time-delay/azimuth space could be reasonably approximated by transformed Gaussian error distributions in state space. However, for data with large measurement azimuthal uncertainties, this becomes a poor assumption. This work compares results from a previous study that applied ML-PDA in a Cartesian implementation to the Metron 2009 simulated dataset against ML-PDA applied to the same dataset but with the algorithm implemented in time-delay/bearing space. In addition to the Metron dataset, a multistatic Monte-Carlo simulator is used to create data with properties similar to that in the Metron dataset to statistically quantify the performance difference of ML-PDA operating in Cartesian state-space against that of ML-PDA operating in measurement-based (time-delay/bearing) state-space.

8393-19, Session 3

Self-organizing radar resource management in constrained multisensor networks with variable, per-node implementations

B. S. Weir, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Multisensor fusion using networks of highly capable, multifunction radars provides an extremely accurate air picture for situational awareness, common track numbering, and engagement support. To-date, resource management capabilities for those multifunction radars have focused on local-only operations, rather than network-centric operations, with multisensor information fusion as an “add-on” functionality.

Prior publications by the authors have shown that resource management in these types of sensor networks can be achieved through self-organization, where each sensor acts independently but in response to knowledge of the behaviors of other sensor s (i.e., in response to the multisensor track picture). Research has shown that self-organization is effective, scalable, and quite useful from a systems engineering and implementation standpoint.

Those past results have often assumed idealistic behaviors from the networking function and consistent implementations. With this paper, we consider the impact of actual network latencies, throughput limitations, and variable rule implementation at the sensor nodes. Further, we consider the impact of covariance consistency on resource decisions, as filter implementation can often diverge from actual target behavior.

8393-20, Session 3

Information-based data prioritization in distributed tracking systems

N. Coult, A. Poore, J. N. Knight, W. Leed, S. Danford, Numerica Corp. (United States)

Effective multi-sensor, multi-target, distributed composite tracking requires the management of limited network bandwidth. In this paper we derive from first principles a value of information for measurements that can be used to sort the measurements in order from most to least valuable.

We show the information metric must account for the models and filters used by the composite tracking system; we then derive instances of the this metric for several filters including the extended Kalman filter (EKF) and the interacting multiple model filter (IMM). We describe how this value of information can be used to optimize bandwidth utilization and illustrate its effectiveness using simulations that involve lossy and latent network models.

8393-32, Session 3

Particle filter tracking for very long-range radars

K. Romeo, P. Willett, Y. Bar-Shalom, Univ. of Connecticut (United States)

In this paper we present an approach for tracking in very long range radar scenarios. We show that in these scenarios the extended Kalman filter is not desirable as it suffers from major consistency problems, and that particle filters may suffer from a loss of diversity among particles after resampling. This leads to sample impoverishment and the divergence of the filter. In the scenarios studied, this loss of diversity can be attributed to the very low process noise. However, a regularized particle filter is shown to avoid this diversity problem while producing consistent results.

8393-29, Poster Session

Three plot correlation-based small infrared target detection in dense sun-glint environment for infrared search and track

S. Kim, Yeungnam Univ. (Korea, Republic of); T. L. Song, Hanyang Univ. (Korea, Republic of); B. Choi, Samsung Thales Co., Ltd. (Korea, Republic of); B. Lee, Agency for Defense Development (Korea, Republic of)

This paper presents a separate spatio-temporal filter based small infrared target detection method to address the sea-based infrared search and track (IRST) problem in dense sun-glint environment. It is critical to detect small infrared targets such as sea-skimming missiles or asymmetric small ships for national defense. On the sea surface, sun-glint clutters degrade the detection performance. Furthermore, if we have to detect true targets using only three images with a low frame rate camera, then the problem is more difficult. We propose a novel three plot correlation filter and statistics based clutter reduction method to achieve robust small target detection rate in dense sun-glint environment. At the top component level, it consists of a geometric processing part for sea region extraction, spatial filtering part, plot correlation-based temporal filtering part, and statistics-based clutter rejection part.

We validate the robust detection performance of the proposed method via real infrared test sequences including synthetic targets.

8393-31, Poster Session

A fast coalescence-avoiding JPDAF

K. Romeo, D. Crouse, Y. Bar-Shalom, P. Willett, Univ. of Connecticut (United States)

In this paper we present a new algorithm for approximating the target-measurement association probabilities of the Joint Probabilistic Data Association Filter (JPDAF). This algorithm is designed to robustify the JPDAF against track coalescence which can greatly degrade the performance of the JPDAF and other approximate algorithms. It is based on the works of Roecker and the JPDAF* of Blom and Bloem. We compare our new algorithm with the two it is based on, as well as the "cheap JPDAF" and the Set JPDAF, and show that it offers a significant improvement in computational complexity over the JPDAF*, and improvement in tracking error over the Roecker algorithm. We compare their performance with respect to the Mean Optimal Subpattern Assignment (MOSPA) statistic in scenarios involving several closely-spaced targets. A consistency comparison of the various algorithms considered is also presented.

8393-33, Poster Session

A survey of maneuvering target tracking, part VIc: approximate nonlinear density filtering in discrete time

X. Li, V. Jilkov, The Univ. of New Orleans (United States)

This paper is Part VIc of a comprehensive survey of maneuvering target tracking without addressing the so-called measurement-origin uncertainty. It provides an in-depth coverage of various approximate density-based nonlinear filters in discrete time developed particularly for handling the uncertainties induced by potential target maneuvers as well as nonlinearities in the dynamical systems commonly encountered in target tracking. An emphasis is given to more recent results, especially those with good potential for tracking applications. Approximate techniques for density-based nonlinear filtering in mixed time have been covered in a previous part. Sampling-based nonlinear filtering will be surveyed in a forthcoming part.

8393-21, Session 4

Exploratory joint and separate tracking of geographically related time series

B. Balasingam, P. Willett, Univ. of Connecticut (United States); G. M. Levchuk, J. Freeman, Aptima, Inc. (United States)

Target tracking techniques have usually been applied to physical systems via radar, sonar or imaging modalities. But the same techniques - filtering, association, classification, track management - can be applied to non-traditional data such as one might find in other fields such as economics, business and national defense.

In this paper we explore a particular data set. The measurements are time series collected at various sites; but other than that little is known about it. We shall refer to as the data as representing the number of taxis observed per unit time at various street corners in New York City. We pose such questions as

1. Which street corners seem to have a common model?
2. Do any corners change their models with time?
3. Are some street corners stochastically linked? That is, do we observed a lack of cabs at one corner as implying a surfeit of cabs elsewhere?
4. Can taxis be tracked even if some data is mislabeled?
5. Can cab behavior be predicted, and if so, how far to the future?

The observations seem well modeled as hidden Markov. This HMM modeling is compared to other approaches; and tests are continued to other (albeit self-generated) data sets with similar characteristics.

8393-22, Session 4

Estimating trackability

J. R. Van Zandt, The MITRE Corp. (United States)

Target tracking sensors and algorithms are usually evaluated using Monte Carlo simulations covering a large parameter space. We show a tracker for which the evaluation can be greatly simplified. We apply it to a ground target tracking problem, and estimate the probability that measurements and tracks are incorrectly associated.

Where only position is measured, we find the probability of a mis-association is a very simple analytic function of the relevant parameters: measurement standard deviation, measurement interval, target density, and target acceleration. For normally distributed target velocities, the average time between misassociations also has a simple form.

8393-23, Session 4

Prediction, tracking, and retrodiction for path-constrained targets

K. Krishanth, R. Tharmarasa, McMaster Univ. (Canada); P. Valin, Defence Research and Development Canada, Valcartier (Canada); E. Meger, exactEarth Ltd. (Canada); T. Kirubarajan, McMaster Univ. (Canada)

This paper presents algorithms for tracking, prediction and retrodiction for targets whose motion is constrained by external conditions (e.g., shipping lanes, roads). The targets are moving along a path, defined by way-points and segments. Measurements are obtained by sensors at low revisit rates (e.g., spaceborne). Existing tracking algorithms assume that the targets follow the same motion model between successive measurements, but in a low revisit rate scenario targets may change the motion model between successive measurements. The proposed prediction algorithm addresses this issue by considering possible motion model whenever targets move to a different segment. Further, when a target approaches a junction, it has the possibility to travel into one of the multiple segments connected to that junction. To predict the probable locations, multiple hypotheses for segments are introduced

and a probability is calculated for each segment hypothesis. When measurements become available, segment hypothesis probability is updated based on a combined mode likelihood and a sequential probability ratio test is carried out to reject the hypotheses with low probability. Retrodiction for path constrained targets is also considered, because in some scenarios it is desirable to find out the target's exact location at some previous time (e.g., at the time of an oil leakage). A retrodiction algorithm is also developed for path constrained targets so as to facilitate motion forensic analysis. Simulation results are presented to validate the proposed algorithm.

8393-24, Session 4

Data modeling for nonlinear track prediction of targets through obscurations

H. M. Jaenisch, Licht Strahl Engineering, Inc. (United States) and Johns Hopkins Univ. (United States); J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We introduce a novel tracking algorithm for complicated and highly dynamic tracks that uses transfer function based predictive Data Models of short segments of track history. When the 2d covariance and sample statistics (Heptor) are acquired for the historical window a behavior based expectation model is derived that forma a model for template based matching and comparison around a perimeter where track was lost. By using the nonlinear track predicted forecast the search window is constrained to areas of likely emergence to enable fast reacquisition and continued track. Spoofing methods such as (single track in and multi-out track out), (track route cross-over) and (many in - one out) are examined and our encouraging results presented.

8393-25, Session 4

Stochastic data association in multitarget filtering

S. P. Coraluppi, C. A. Carthel, Compunetix, Inc. (United States)

Multi-target filtering for closely-spaced targets leads to degraded performance with respect to single-target filtering solutions, due to measurement provenance uncertainty. Soft data association approaches like the probabilistic data association filter (PDAF) suffer track coalescence. Conversely, hard data association approaches like multiple-hypothesis tracking (MHT) suffer track repulsion. We introduce the stochastic data association filter (SDAF) that utilizes the PDAF weights in a stochastic, hard data association update step. We find that the SDAF outperforms the PDAF, though it does not match the performance of the MHT solution. We compare as well to the recently-introduced equivalence-class MHT (ECMHT) that successfully counters the track repulsion effect [1]. Simulation results are based on the steady-state form of the Ornstein-Uhlenbeck process, allowing for lengthy stochastic realizations with closely-spaced targets. Performance analysis is with respect to the mean optimal subpattern assigment (MOSPA) metric.

The initial motivation in developing the SDAF was to identify a filtering solution that would perform like the ECMHT in the case in which multiple synchronous sensors are not available. In truth, the ECMHT provides a much more high-performing and interesting solution scheme to the SDAF. Nonetheless, the SDAF does have some merit: it outperforms the PDAF, its coalescence characteristics are less severe than those of the PDAF, and it introduces a rather unusual stochastic filtering solution, something that is rarely found in the tracking and filtering literature.

[1] S. Coraluppi and C. Carthel, An Equivalence-Class Approach to Multiple-Hypothesis Tracking, submitted to IEEE Aerospace Conference, Big Sky MT, USA, March 2012.

8393-26, Session 4

Histogram PMHT for correlated targets

S. Davey, N. Gordon, Defence Science and Technology Organisation (Australia)

Histogram PMHT is an efficient algorithm for multi-target track-before-detect and has been shown to give detection sensitivity similar to numerical approximations to the optimal Bayesian filter. However, it assumes that the targets move independently, which is not always the case. The paper applies Histogram PMHT to the group tracking problem, where target move in a dynamic formation. In particular, the problem of tracking complicated extended objects in video imagery is addressed where the object shape is approximated as a Gaussian mixture and the components of the mixture are tracked as a group of targets with a correlated motion model.

8393-27, Session 4

An approximate CPHD filter for superpositional sensors

R. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); A. I. El-Fallah, Scientific Systems Co., Inc. (United States)

Most multitarget tracking algorithms, such as JPDA, MHT, and the PHD and CPHD filters, presume the following measurement model: (a) targets are point targets, (b) every target generates at most a single measurement, and (c) any measurement is generated by at most a single target.

However, the most familiar sensors, such as surveillance and imaging radars, violate assumption (c).

This is because they are actually superpositional-that is, any measurement is a sum of signals generated by all of the targets in the scene. At this conference in 2009, the first author derived exact formulas for PHD and CPHD filters that presume general superpositional measurement models.

Unfortunately, these formulas are computationally intractable. In this paper, we modify and generalize a Gaussian approximation technique due to Thouin, Nannuru, and Coates to derive a computationally tractable superpositional-CPHD filter. Implementation of the superpositional-CPHD filter, as well as its PHD filter special case, requires sequential Monte Carlo (particle filter) techniques.

Conference 8394: Algorithms for Synthetic Aperture Radar Imagery XIX

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8394-01, Session 1

Approximation and bounding of distortion errors in polar format SAR imaging for squinted geometries

M. Horvath, Wright State Univ. (United States) and MacAulay-Brown, Inc. (United States); B. Rigling, Wright State Univ. (United States)

It has been shown in the past that the planar wavefront assumption in polar format imaging yields spatially variant phase errors that will lead to distortion and defocus in the resulting image. These side-effects can be partially compensated for in a post-filtering process with knowledge of the spatially variant phase error function. In this paper, we focus on distortion specifically that causes an unwanted geometric warping of the resulting image. A Taylor series expansion procedure on a differential range error term is used to approximate the spatially-variant phase error function. With this approximation, a scene size bound is derived limiting the visible distortion in the image. Next, the differential range error term approach is compared to the conventional approach of assuming a dominant quadratic error term in terms of accurately approximating the actual distortion. Lastly, the differential range error term approach is used to bound scene size with the conventional quadratic distortion correction applied. Simulation examples are included.

8394-02, Session 1

Dual format algorithm implementation with gotcha data

L. Gorham, Air Force Research Lab. (United States); B. Rigling, Wright State Univ. (United States)

No abstract available

8394-03, Session 1

A transformation between on-center and off-center point scatterers for circular SAR

L. J. Moore, Air Force Research Lab. (United States)

No abstract available

8394-04, Session 1

Preliminary evaluation of SAR image compression performance using MatrixView on coherent change detection

A. Thiagarajan, MatrixView Ltd. (Singapore); L. Gorham, Air Force Research Lab. (United States)

No abstract available

8394-05, Session 1

Complex synthetic aperture radar data compression using compressive sensing techniques

P. L. Poehler, SAIC (United States)

Existing compression algorithms, primarily designed for visible electro-optical (EO) imagery, do not perform well for Synthetic Aperture Radar (SAR) data. Unlike EO imagery, where each pixel is represented by a single value, SAR imagery contains two components: In-Phase (I) and Quadrature (Q) or Magnitude (M) and Phase (ϕ). The best compression ratios achieved to date are less than 10:1 with minimal degradation to the phase data. The 2-D frequency transform method is used with non-linear sampling to form the DCT coefficients and then pose and solve a compressive sensing basis linear system which performs the transform. This is employed in two ways:

1) With a lattice filter, quantizer and Huffman coder and,

2) With optimum (MMSE sense) quantization and Huffman code). coding

Results are then numerically compared with metrics against standard techniques JPEG, J2K.

This paper presents results obtained using new compressive sensing techniques in combination with complex SAR data compression algorithms designed specifically to compress complex SAR imagery, while preserving both magnitude and phase information at compression ratios of 20:1 and better. A brief discussion is provided explaining the compression problems posed by complex data, a review of present algorithms and their limitations, and, finally, a description of a new compressive sensing algorithm approaches. Results are presented for several implementations of this technique.

8394-06, Session 1

Sparse and accurate SAR image reconstruction

D. Vu, K. Zhao, J. Li, Univ. of Florida (United States)

We investigate the usage of a high resolution method, the Iterative Adaptive Approach (IAA), in combination with a maximum a posteriori (MAP) method to reconstruct SAR images that are both sparse and accurate. IAA is a nonparametric weighted least squares algorithm that is robust and user parameter free. IAA has been shown to reconstruct dense and accurate SAR images with excellent side lobe suppression and high resolution enhancement. We first reconstruct the SAR images using IAA and then we enforce sparsity by using MAP with a sparsity inducing prior. The MAP approach is also user parameter free. By coupling these two methods, we can produce sparse and accurate SAR images that are conducive for feature extraction and target classification applications. In addition, we show how IAA can be made computationally efficient without sacrificing accuracies, a desirable property for SAR applications where we encounter (phase history) data matrices with large dimensions. We demonstrate the success of our approach using the Air Force Research Lab's "Gotcha Volumetric SAR Data Set Version 1.0" challenge dataset. We show that for individual vehicles contained in the scene, clear edges and boundaries of the vehicles can be obtained with our approach.

8394-07, Session 1

Reconstruction of interrupted SAR imagery for persistent surveillance change detection

I. Stojanovic, W. C. Karl, Boston Univ. (United States); L. Novak, Scientific Systems Co., Inc. (United States)

No abstract available

8394-08, Session 2

Flying blind: a challenge problem for SAR imaging without navigational data

B. Rigling, Wright State Univ. (United States)

Developers have been increasingly successful at installing SAR systems on small UAVs. Within that domain, there is a continuous drive to make systems smaller and cheaper in order to minimize the value of assets placed at risk. We would therefore like to reduce the SAR system hardware to the minimal complement required to form a useful image. As inertial navigation/motion units can significantly add to platform size, weight, and cost, developing data-adaptive approaches to form useful imagery with minimal navigational inputs is desirous. This paper outlines a challenge problem to focus research efforts towards that end.

8394-09, Session 2

Autofocus algorithm for curvilinear SAR imaging

E. H. Bleszynski, M. K. Bleszynski, T. Jaroszewicz, Monopole Research (United States)

We describe an approach to autofocusing for large apertures on curved

SAR trajectories. It is a phase-gradient type method in which phase corrections compensating trajectory perturbations are estimated not directly from the image itself, but rather on the basis of “partial” SAR data -- functions of the slow and fast times -- reconstructed (by an appropriate forward-projection procedure) from windowed scene patches, of sizes comparable to distances between distinct targets or localized features of the scene. The resulting “partial data” can be shown to contain the same information on the phase perturbations as that in the original data, provided the frequencies of the perturbations do not exceed a quantity proportional to the patch size.

The algorithm uses as input a sequence of conventional scene images based on moderate-size subapertures constituting the full aperture for which the phase corrections are to be determined. The subaperture images are formed with pixel sizes comparable to the range resolution which, for the optimal subaperture size, should be also approximately equal the cross-range resolution. The method does not restrict the size or shape of the synthetic aperture and can be incorporated in the data collection process in persistent sensing scenarios.

The algorithm has been tested on the publicly available set of GOTCHA data,intentionally corrupted by random-walk-type trajectory fluctuations (a possible model of errors caused by imprecise inertial navigation system readings) of maximum frequencies compatible with the selected patch size. It was able to efficiently remove image corruption for apertures of sizes up to 360 degrees.

8394-10, Session 2

Multistatic synthetic aperture radar interferometry

H. C. Yanik, B. Yazici, Rensselaer Polytechnic Institute (United States)

Interferometric synthetic aperture radar (IFSAR) imagery is a technique to determine the topography of a scene and its deformation over time [1]. An IFSAR image is formed by processing the phases of two or more complex SAR images that are obtained with antennas at different heights. Typical IFSAR data is collected by a monostatic SAR system either by traversing a similar trajectory twice (repeat pass interferometry) or by two tandem antennas (single pass interferometry). In this paper, we propose a novel method to perform multi-static IFSAR imagery.

We assume that multiple receiving and transmitting antennas working in a multi-static mode are traversing over the scene of interest and making multiple passes over a period of time. We perform a spatio-temporal correlation of the received signal measured by different receivers for each pass as well as for different passes. This results in a novel model that relates the correlated signal to ground topography and deformation rate. We next use generalized likelihood ratio test (GLRT) to estimate topography and deformation rate as well as the radiance of the scene.

We present numerical simulations to demonstrate the performance of the proposed method.

References

[1] R. Hanssen, Radar interferometry: data interpretation and error analysis. Kluwer Academic Pub, 2001, vol. 2.

8394-11, Session 2

Bistatic SAR coherence over nonplanar topographies

D. B. Andre, Defence Science and Technology Lab. (United Kingdom); K. Morrison, Cranfield Univ. (United Kingdom)

Monostatic Synthetic Aperture Radar (SAR) Coherent Change Detection (CCD) has been found to be of great utility in detecting changes that occur on the ground. The CCD procedure involves performing repeat pass radar collections to form a coherence product, where ground disturbances can induce detectable incoherence. However there is usually a difference in the radar collection geometry which can lead to incoherent energy noise entering the CCD, which reduces the detectability of the disturbances. When sensing flat terrain, the incoherence due to collection geometry difference can be removed through a straightforward Fourier image support trimming process. However, it has been found that when the terrain contains non-flat topography, the optimal trimming process is substantially more involved, so much so that a new per-pixel SAR back-projection imaging algorithm has been developed. This algorithm trims off incoherent energy on a per-pixel basis according to the local topography [1].

In this paper the author extends the monostatic per-pixel formalism and algorithm to the bistatic SAR scenario. Bistatic scenarios are not only of theoretical interest. Sometimes this is the only option available due to stealthy collection requirements amongst other reasons. This paper reports results from a bistatic CCD study, demonstrating the extension of monostatic non-flat terrain coherence concepts and demonstrating that different bistatic geometry collections can be coherent with each other. Experimental results are provided for validation.

1. D. Blacknell, D. B. Andre and C. M. Finch, “SAR Coherence Change Detection (CCD) over Mountainous Regions”, International Conference Synthetic Aperture Sonar and Synthetic Aperture Radar (SAS/SAR), 13th - 14th September 2010, Lerici, Italy

8394-12, Session 2

Bistatic SAR imaging of the lunar surface using the Aerocibo Observatory transmitter and the lunar reconnaissance orbiter receiver

C. V. Jakowatz, Jr., D. E. Wahl, Sandia National Labs. (United States); D. A. Yocky, Sandia National Labs (United States)

Polarimetric bistatic SAR imaging of the lunar surface may allow

detection of ice at the bottom of certain craters. We have employed the Aerocibo Observatory radar transmitter and the Lunar Reconnaissance Orbiter as a receiver to collect such bistatic data of the lunar surface. In this paper we demonstrate the abiltiy to form bistatic polarimetric imaergy with spatial resolution on the order of 50m, and to create polarimetric maps that could potentially reveal the presence of crater ice. We discuss the details of the signal processing techniques that are required to allow these products to be formed. The image fomation paradigm of backprojection is well-suited to this particular strip-map bistatic collection geometry. Various preprocessing steps, including tracking the direct-path signal for purposes of phase synchronization between transmitter and receiver, are discussed.

8394-13, Session 3

Passive synthetic aperture radar imaging of ground moving targets

S. Wacks, B. Yazici, Rensselaer Polytechnic Institute (United States)

In this paper we present a method for imaging ground moving targets using passive synthetic aperture radar. A passive radar imaging system uses small, mobile receivers that do not radiate any energy. For these reasons, passive imaging systems result in significant cost, manufacturing, and stealth advantages. The received signals are obtained by multiple airborne receivers collecting scattered waves due to illuminating sources of opportunity such as commercial television, FM radio, and cell phone towers. We describe a novel model for the received data and a corresponding method for image reconstruction. Numerical simulations are then performed to show the efficacy of the system.

Our model first allows for multiple receivers to collect data along arbitrary, but known flight trajectories. The sources of opportunity are assumed to be stationary illuminators. Our model is then completed by performing a spatio-temporal correlation on each pair of receivers, which eliminates all transmitter-dependent terms in the phase of the resulting signal. The inversion process is derived analytically with a filtered backprojection (FBP) method. The velocities of the targets are estimated along with the scene reflectivity.

This radar imaging system uses multiple moving passive receivers and images a scene with multiple targets moving at different velocities. The passive imaging method can accomodate arbitrary flight trajectories, antenna beam patterns, and a non-flat ground topography.

8394-14, Session 3

Three-channel processing for improved localization performance in SAR-based GMTI

R. W. Deming, U.S. Air Force (United States)

This paper describes a technique for detecting and localizing slowly-moving targets in cultural clutter using synthetic aperture radar (SAR) data. Here, single-pass data from multiple receive channels are jointly processed, where channels are spatially offset in the along-track direction. At last year's SPIE conference [1] we described a two-channel processing method which was a hybrid of two existing techniques; the displaced phase center antenna (DPCA) technique and along-track SAR interferometry (AT-InSAR). Using Gotcha Challenge data [2], we showed that two-channel processing could be used to reliably detect moving vehicles, even in difficult cases when their signatures are completely obscured by clutter. Unfortunately, localization can be problematic when using two-channel processing since overlapping clutter corrupts the measurement of the AT-InSAR phase, thereby making it difficult to place targets in azimuth. In the present paper we show that by performing three-channel processing in an appropriate manner, clutter effects can be diminished and significant improvement can be obtained in azimuth localization accuracy. The three-channel processing consists of two separate stages; (i) perform DPCA separately on channel pairs {1 2} and {2 3}, then (ii) perform AT-InSAR on the result. This architecture differs from last year's two-channel method in which both DPCA and AT-InSAR were performed in parallel during a single stage. We demonstrate the three-channel method on Gotcha SAR-based GMTI Challenge data [2]. The method is computationally efficient since the main processing step is a two-dimensional FFT.

[1] Deming, R., ``Along-Track Interferometry for Simultaneous SAR and GMTI: Application to Gotcha Challenge Data,” Proc. SPIE 8051, 80510P (2011).

[2] S. Scarborough, et al, “A challenge problem for SAR-based GMTI in urban environments,” Proc. SPIE, Vol. 7337 (2009).

8394-15, Session 3

Detection and tracking of prominent scatterers in SAR data

B. Shapo, Integrity Applications, Inc. (United States); M. Stuff, Michigan Tech Research Institute (United States); C. Kreucher, R. Majewski, Integrity Applications, Inc. (United States)

Tracking prominent scatterers in range can have many applications in SAR data collections. Here, we address motion estimation from radar signals for maneuvering platforms that may lack adequate inertial/GPS information. Our approach estimates range histories of multiple isolated scatterers with high accuracy, and solves for three-dimensional motion by geometric inversion.

For high-accuracy scatterer range tracking, we employ an automated CFAR criterion algorithm for detecting prominent scatterers, followed by a two-input Kalman Filter (KF) tracking stage. These two steps, performed in concert, allow tracking multiple scatterer ranges over multiple SAR pulses. The KF state space is range and range-rate. Data inputs to the algorithm derive from multiple SAR pulses, broken into Coherent Processing Intervals (CPI). At each CPI, scatterer peak amplitude and phase are available to the algorithm, and these serve as the two inputs. Peak amplitude locations and phase changes provide updates to the scatterer range and range-rate estimates, respectively.

Geometric inversion processes the prominent scatterer estimated ranges, and enables remote size and shape measurements for three-dimensional scattering center configurations. In addition, it permits estimating the three-dimensional relative motions of the radar platform. We compare methods utilizing nonlinear optimization algorithms that are based on invariant theory.

8394-16, Session 3

Detection and imaging of multiple ground moving targets using ultra-narrowband continuous-wave SAR

L. Wang, Nanjing Univ. of Aeronautics and Astronautics (China); B. Yazici, Rensselaer Polytechnic Institute (United States)

Ground moving target detection and imaging using synthetic aperture radar (SAR) has received considerable attention in the past two decades [1-16]. However, all the existing techniques are for traditional synthetic aperture radar (SAR) systems, which accomplish high-range resolution imaging of static scenes and moving targets by transmitting wideband waveforms. We consider the problem of synthetic aperture moving target detection and imaging using ultra-narrowband CW waveforms. Such a SAR system requires relatively simple and low-cost transmitter, and in some cases does not need a dedicated transmitter. Existing radio frequency signals, such as radio, television signals, WiFi signals, etc. can be used as the transmission sources. Additionally, ultra-narrowband continuous waveforms have high Doppler resolution and are capable of capturing the velocity information of the moving targets as compared to the high range resolution waveforms used by the traditional SAR systems.

In [17], we presented a novel synthetic aperture imaging method of stationary scenes that takes advantage of the high Doppler resolution of the transmitted ultra-narrowband continuous waveforms. In this paper, we consider the moving target detection and imaging problem using such SAR systems. Our approach exploits the high Doppler resolution of the transmitted waveforms to reconstruct the reflectivity (position), as well as to estimate the velocity field of moving targets. We develop a novel model that relates the velocity field and the reflectivity of the scene to a correlated received signal and a corresponding FBP-type novel image formation method. A set of FBP images are reconstructed with hypothesized velocities that cover the expected velocity range. Moving targets are well focused in the reflectivity images corresponding to their velocities. We use the image contrast as a metric to detect targets and to determine their velocities. We present numerical experiments to demonstrate the performance of the moving target detection and imaging method. To the best of our knowledge, our method is the first in the literature that addresses the ground moving target detection and imaging using such SAR systems. It has several advantages over existing methods which we will discuss in detail in the conference paper.

8394-17, Session 3

Separation of vibrating and static SAR object signatures via an orthogonal subspace transformation

M. P. Pepin, M. M. Hayat, The Univ. of New Mexico (United States)

When vibrating objects are present in a Synthetic Aperture Radar image they induce a modulation in the pulse-to-pulse Doppler collected. At higher frequencies (up to a sampling limit dictated by half the PRF) the modulation is low amplitude and swamped by the Doppler from static objects (clutter). This paper presents an orthogonal subspace transform that separates the modulation of a vibrating object from the static clutter. After the transformation the major frequencies of the vibration are estimated with asymptotically (as the number of pulses increases) decreasing variance and bias.

Although the effects and SAR image artifacts from vibrating objects are widely known their utility has been limited to high signal-to-noise, low frequency (high energy) vibrating objects. The method presented here increases the minimum required signal-to-noise ratio of the vibrating object by up to 20 dB over other methods. Additionally vibrations over the full (azimuth-sampled) frequency range from one over the aperture time to half the pulse repetition frequency (PRF) are equally measured with respect to the noise level at each specific frequency. After separation of the vibrating and static object signal sub-spaces any of the numerous available spectral estimation methods can be applied to estimate the vibration spectrum from the data.

8394-18, Session 3

A Bayesian method for polarimetric SAR calibration

E. Ertin, The Ohio State Univ. (United States)

No abstract available

8394-19, Session 3

Extensions to persistent change detection in SAR imagery with posterior models

G. E. Newstadt, Univ. of Michigan (United States)

No abstract available

8394-20, Session 3

A synopsis of challenge problems

B. Gorham, Air Force Research Lab. (United States)

No abstract available

8394-21, Session 4

Wide angle SAR ATR challenge problem

K. E. Dungan, High Performance Technologies, Inc. (United States); L. Gorham, S. M. Scarborough, J. Parker, Air Force Research Lab. (United States); J. Nehrbass, High Performance Technologies, Inc. (United States); J. N. Ash, The Ohio State Univ. (United States)

No abstract available

8394-22, Session 4

Filtered back-projection type, direct-edge detection of real synthetic aperture radar images

N. Pena, G. Garza, Z. Qiao, The Univ. of Texas-Pan American (United States)

Edge detection algorithms applied to Synthetic Aperture Radar (SAR) images have many applications. Detecting edges is an important task in processing images in order to see objects from SAR data. In this work, the received data is first filtered and then backprojected. The edges are detected in both the x and y directions and results shown. SAR segmented images generated using this technique, are provided from a publicly available SAR dataset. The authors of this technique had applied it to synthetic data; in this work the process is applied on real SAR data with significant results.

8394-23, Session 4

Region-based target detection approach for synthetic aperture radar images and its parallel implementation

O. E. Okman, C. Demirkesen, F. Nar, SDT A.S. (Turkey); M. Cetin, Sabanci Univ. (Turkey)

Most of the constant false alarm rate (CFAR) based automatic target detection (ATD) algorithms in the literature assume a homogeneous background clutter and a priori knowledge about the target size and shape. In this study, we propose a CFAR-based ATD approach that adaptively determines the target shape and clutter regions by utilizing a region growing method and performing hypothesis testing based on the background model. Through this procedure, it is possible to detect various types of targets of different shapes and sizes.

To initiate the process, the brightest pixels in a 5x5 neighborhood are selected as candidate targets and candidate target regions are formed by growing each candidate. Then, clutter regions around each of the candidate target are determined by checking certain predefined conditions. In this process, it is assumed that the intensities of despeckled pixels in the clutter regions change slowly and the size of these regions should be comparably large with respect to the corresponding target size. Finally, if the ratio between the average intensities of a candidate target and its corresponding clutter region is above a certain threshold, it is declared as a target.

We have performed comparisons of the proposed approach with existing CFAR-based methods in terms of detection performance and computational load. These experiments demonstrate the improved target detection performance provided by the proposed approach. Since the proposed algorithm requires more computational power than existing methods, we have parallelized the approach to increase its computational efficiency. We demonstrate the resulting the speed ups using OpenMP and NVidia CUDA implementations of the algorithm.

8394-24, Session 4

Target DNA: characterization of angle-diverse radar signatures

E. Ertin, The Ohio State Univ. (United States)

No abstract available

8394-25, Session 4

Simultaneous tracking and recognition performance model

B. Kahler, SAIC (United States)

High value target tracking and identification (ID) performance is impacted by sensor, target, and environmental conditions. Radar sensors are preferred since they provide sensor capabilities over a wide range of weather conditions. Sensor management provides some control, such as adjustment of the collection geometry. However, ground target dynamics and the collection environment can't be controlled and degrade tracking and identification performance such as when the target maneuvers into dense traffic, stops at intersections, or is traveling in a cluttered environment and is obscured by vegetation or buildings. Target identification algorithms using high range resolution (HRR) profiles formed from moving target data and range profiles formed from synthetic aperture radar (SAR) data have been demonstrated. Feature Aided Tracking (FAT) exploits the features derived from HRR data to improve target tracking. Identifying the dominant features which can be reliably exploited when a target is either moving or stationary that can then be used to maintain track and ID the target is expected to enhance algorithm performance in realistic scenarios. A simultaneous tracking and recognition (STAR) performance model is developed and applied to realistic scenarios to provide performance gain estimates based on the number of exploited features and operating conditions. This paper presents performance results for simultaneous target tracking and identification using HRR and SAR sensor data.

8394-27, Session 4

Classifying circular SAR images using sparsity

C. Paulson, Univ. of Florida (United States); E. G. Zelnio, L. Gorham, Air Force Research Lab. (United States); D. Wu, Univ. of Florida (United States)

In this paper, classification of civilian vehicles using Circular Synthetic Aperture Radar (CSAR) images will be investigated. The problem we are addressing is classifying civilian vehicles of CSAR images at scene center and estimating the pose of the vehicle. Traditionally, SAR classification research has focused on narrow aperture images of military vehicles which have lots of angles, corners, and flat plates; therefore, only needing a narrow aperture to generate decipherable images. Whereas the smooth surfaces of civilian vehicles requires an approach that uses significantly more aperture to, in effect, diffusely illuminate the vehicle surfaces by flying the radar around the target. Our approach is to use the facet models of civilian vehicles to efficiently create CSAR angle templates as training data rather than using measure or synthetic data like other algorithms that have been developed. Using the templates will significantly reduce the time and cost to do the classification of SAR images. The classification approach leverages the physical understanding of the SAR imaging process as well as recent advances in using sparsity constraints in recognition algorithms.

8394-28, Session 4

Performance estimation of SAR using NIIRS techniques

A. R. Nolan, Etegent Technologies, Ltd. (United States)

In this paper, we define a relationship between SAR image formation parameters and the utility of the resulting imagery. This is performed by deriving a series of General Image-Quality Equations, or GIQEs from the underlying information content in the data. The information theoretic GIQEs are fit to observed data obtained both from sensor exploitation algorithms and image analysts. The utility of this approach is demonstrated over a variety of image resolutions, sensor elevations, and noise characteristics.

8394-29, Session 4

Sub-voxel registration for volumetric SAR imagery

C. E. Frost, Scientific Systems Co., Inc. (United States)

Recent research has produced techniques for generating focused volumetric SAR images from multi-pass circular SAR data collections. Focused volumetric SAR images are formed by coherently aligning vertical stacks of 2D SAR images from multiple passes and optimizing the volumetric SAR image focus. During this coherent alignment process the volumetric SAR image is also shifted within the output image sampling grid to produce an optimal image focus. Volumetric SAR images formed from different viewing geometries will have different shifts. Volumetric SAR image exploitation often involves combining multiple volumetric SAR images. In order to combine multiple coherently aligned volumetric SAR images for exploitation, these images must be registered to one another. Volumetric SAR images formed from two-dimensional SAR images with overlapping apertures correlate well with each other.

Algorithms are presented here that efficiently provide three-imensional sub-voxel estimates of the correlation peak location or the relative image shift using digital Fourier transform matrices.

8394-30, Session 4

Combination of different SAR modalities for geospatial intelligence applications in a harbor environment

D. C. Borghys, M. Shimoni, C. Perneel, Royal Belgian Military Academy (Belgium)

Since the launch of Terrasar-X, Radarsat 2 and the Cosmo-Skymed constellation, spaceborne SAR data with a high spatial resolution have become more readily available.

The current paper investigates the use of such data for geopspatial intelligence applications in a harbor environment. Applications of interest include change detection, activity monitoring and global scene understanding. The analysis is based on a set of more than twenty datasets from the three abovementioned satellite systems, acquired over a period of 30 days over the sea harbour of Zeebruges in Belgium. Most datasets are HiRes spotlight mode, but some scansar and full-polarimetric data are also available.

The HiRes spotlight data allow to monitor activity of ships, cars and cranes within the port.

The scansar images are used for ship detection in the English channel. Several ship detection algorithms are implemented and compared with respect to each other. AIS data, acquired at the SAR overpass times is used for validating detection results.

The PolSAR image is combined with a LIDAR DEM of the area as well as with the HiRes spotlight data for global scene understanding of the harbor environment using a joint feature/object based classification.

8394-31, Session 4

Robust 3D reconstruction using lidar and polarized image

P. Duraisamy, Univ. of North Texas (United States); M. S. Alam, Univ. of South Alabama (United States)

3-D reconstruction plays vital role in many applications like city planning, heritage, video games and others. The accuracy of 3-D reconstruction is very important to maintain the high quality output. GPS or INS sensors are used to build the 3-D model, but it is a expensive approach. In this paper, we introduce a novel approach without using GPS or INS sensor to build the 3D model. As a first step, We fuse polarized image with LiDAR data to build the rough estimate of the camera matrix. We are introducing the polarized image instead of un-polarized image (regular visual image) to reduce the artifacts created by laser scanning which will refine the rough estimate of the camera matrix. This approach is inexpensive and results are promising compared to existing techniques.

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8395-01, Session 1

Constraining an optical phased array beam control study

D. K. Marker, W. A. Green, Air Force Research Lab. (United States)

An optically phased array is a set of discrete telescopes consisting of multiple lasers, sensors, actuators, and optics whose performance is affected by platform motion, atmospheric distortions, and object disturbances. This combination of hardware and disturbances creates a massive design space and requires the beam control expert to unnecessarily explore the related physics. In this paper a set of constraints will be determined that realistically and substantially limits the design space for an optical phased array beam control subsystem where these restrictions do not hinder beam control innovation. Presented is an approach to limit the research space for a novel phased array optical beam control development.

8395-02, Session 1

Generation of laser beams with controllable space-varying coherence with fiber-array systems

M. A. Vorontsov, Univ. of Dayton (United States); V. V. Kolosov, V. V. Dudorov, V.E. Zuev Institute of Atmospheric Optics (Russian Federation)

The ability to control piston phase at fiber-array systems at rates on the order of GHz opens the potential for the creation of conformal laser beams with spatially-varying coherence properties within the transmitter aperture. For example, one might create a laser beam with a higher degree of spatial coherence in the central area of the aperture and a coherence that declines towards its periphery. We show that laser beams with controllable space-varying coherence (SVC-beams) can provide unique capabilities for agile mitigation of atmospheric and speckle effects in active imaging and laser-based systems. For directed energy applications, a single SVC-beam might be utilized for multiple functions, including speckle-free target active imaging, hit-spot pointing, and atmospheric turbulence and thermal blooming effects mitigation.

8395-03, Session 1

Active multi-aperture imaging through turbulence

N. J. Miller, P. F. McManamon, D. Shemano, J. W. Haus, Univ. of Dayton (United States)

We describe our IMAGE testbed which uses coherent detection of the complex field reflected off a diffuse target with seven hexagonally arranged apertures. The seven measured optical fields are then phased with a digital optimization algorithm to synthesize a composite image whose angular resolution exceeds that of a single aperture. This same post-detection phasing algorithm also corrects aberrations induced by imperfect optics and a turbulent atmospheric path. We present experimental results of imaging diffuse targets in a compact range with two phase screens which simulates a 7 kilometer propagation path through distributed atmospheric turbulence.

8395-04, Session 1

Real-time coherent phased array image synthesis and atmospheric compensation testing

J. J. Widiker, MZA Associates Corp. (United States); N. J. Miller, Univ. of Dayton (United States); M. R. Whiteley, MZA Associates Corp. (United States)

Developments in imaging technology for aircraft-based systems are moving in the direction of a sparse, distributed aperture arrays which are conformal to the shape of the air vehicle. These modular arrays can provide resolution capabilities similar to large monolithic telescope apertures without the associated weight and required aircraft structural modifications. A key challenge of such a system is to accomplish the imaging function without requiring an elaborate optical relay system to bring the receive channels together on a single focal plane array (FPA). To overcome this challenge, phased array imaging systems rely on coherent imaging through holographic detection of the complex optical field such as spatial-heterodyne imaging, which requires a digital processor to synthesize the combined imagery. This approach also allows atmospheric compensation to be included digitally in the image synthesis processing thereby eliminating any latencies due to phase modulation hardware in the subaperture module. To support testing of phased array imaging systems, we have constructed a GPU-based image processor capable of real-time (1 kHz) image synthesis including low-order atmospheric compensation. Using this processor and the IMAGE testbed at UD/LOCI, we demonstrate the effectiveness of our processor and phasing algorithm during scaled testing of a Hex-7 aperture array. We show image synthesis and compensation results from laboratory testing where atmospheric turbulence effects have been induced with phase wheels at varying positions along the propagation path.

8395-05, Session 1

Beam steering and focusing in a spatial heterodyne-based multi-aperture imager

G. M. Wu, Univ. of Dayton (United States)

A multi aperture imaging system with nonmechanical steering device added to each subaperture was considered. Such setup allows for focusing and tracking of a target over a fine angle while preserving high resolution imaging in a compact system. An imaging system has the ability to add digital focus for receiving. However, in the case of transmitting the focus must be provided by optical components. Even when receiving, at a short enough range it might be necessary to introduce optical corrections to avoid phase aliasing. To this end, the effects of implementing a real device such as BNS Spatial Light Modulator (SLM), a reflective 512x512 pixels with 83.4% area fill factor steering device, on the multi aperture imaging system were investigated. The pixelated phase nature of SLM and the use of 2π resets to provide stepped sawtooth phase profiles for steering over a discrete fine angels and stepped parabola phase focusing was modeled. Each pixel of the SLM was modeled by an array of 10x10 elements with 9 active and 1 inactive in both the x and y direction. As expected and shown by the simulation results, the periodic reset of the quadratic phase bowl introduced phase grating modulations, which produces the so call “ghost image” around the center image. By only providing stepped sawtooth profile to steer, the simulation shows that with increasing phase steps within the sawtooth profile the diffraction efficiency increase but at the cost of decreased steering angles. Further, the ability of SLM to correct for aberrations was also investigated.

8395-06, Session 2

The Airborne Aero-Optics Laboratory (AAOL)

E. J. Jumper, S. Gordeyev, M. A. Zenk, D. A. Cavalieri, Univ. of Notre Dame (United States)

This paper will give a brief overview of aero-optic phenomenon and then describe the Airborne Aero-Optics laboratory (AAOL) program as an affordable research tool to measure aero-optical distortions in ground facilities and in flight. The AAOL program includes components in computational and theoretical modeling of aero-optical phenomena, wind-tunnel testing and, most uniquely, flight testing on two, transonic jet aircraft. The paper will briefly mention all aspects of the program but then go more deeply into of aircraft systems, their engineering development and of the various hardware needed to make the program possible and, finally, the evolution of the instrumentation suite used in the main laboratory aircraft. Also included will be a brief review of the type of data that we are now routinely collecting both in the wind tunnel and in flight, with some discussion of the future of the program.

8395-07, Session 2

Recent data from the AAOL

N. DeLucca, S. Gordeyev, E. J. Jumper, M. A. Zenk, D. A. Cavalieri, Univ. of Notre Dame (United States)

In this talk recent in-flight aero-optical measurements on Airborne Aero-Optics Laboratory (AAOL) will be given. Instrumentation and experimental set-up will be presented. Results of extensive survey of aero-optical environment at different viewing angles for both flat-window and conformal-window turrets at different subsonic and low transonic speeds, below M = 0.65, will be presented, compared and extensively discussed. Statistical analysis of wavefronts at different viewing angles will be presented and discussed. A possible extension of subsonic scaling laws to low transonic speeds will be proposed and discussed.

8395-08, Session 3

Spatial and temporal characterization of AAOL flight test data

D. J. Goorskey, MZA Associates Corp. (United States)

This paper discusses spatial-temporal characterizations of recent in-flight AAOL wavefront measurements and implications for adaptive optics (AO) control requirements. The data includes subsonic and transonic, flat and conformal window turret cases, flown at various Mach numbers and altitudes including both static turret angles and slewing maneuvers. The validity of the Mach-squared scaling relation for disturbance magnitude and Strouhal number scaling for temporal frequency will also be addressed. Investigation and characterization of aero-optical/aero-mechanical jitter from the AAOL in-flight wavefronts will be presented. This paper will also examine the susceptibility of AAOL measured aero-optical disturbances to predictive AO control.

8395-09, Session 3

AAOL wavefront data reduction approaches

S. Abado, S. Gordeyev, E. J. Jumper, Univ. of Notre Dame (United States)

This paper discusses various wavefront data reduction approaches for the airborne aero-optics laboratory (AAOL) wavefront data sequences. The proper orthogonal decomposition (POD) analysis utilized to characterize the spatial and temporal content of the wavefronts. Results for different turret viewing angles are to presented and compared.

8395-10, Session 3

Identification, prediction, and control of aero-optical wavefronts

A. Faghihi, J. Tesch, J. S. Gibson, Univ. of California, Los Angeles (United States)

No abstract available

8395-11, Session 3

Recent measurements of aero-optical effects caused by subsonic boundary layers

A. E. Smith, S. Gordeyev, E. J. Jumper, Univ. of Notre Dame (United States)

Results of recent experimental measurements of aero-optical distortions caused by turbulent boundary layers at subsonic speeds M=0.4..0.6 will be presented. Measurements were performed using a high-speed Shack-Hartmann sensor and a Malley probe to collect instantaneous wavefronts with high spatial and temporal resolution. Effects of different aperture sizes on levels of aero-optical aberrations and correlation lengths in both spanwise and streamwise directions will be compared and discussed for both wavefront sensors. Detailed statistical analysis of spatial and temporal spectra of aero-optical distortions will be presented and the contribution of boundary-layer large- and small-scale structures on overall level of aero-optical distortions will be examined and discussed.

8395-12, Session 3

Computational analysis of subsonic-boundary-layer aero-optics

K. Wang, M. Wang, Univ. of Notre Dame (United States)

The aero-optical effects of a Mach 0.5 turbulent boundary layer are analyzed using the fluctuating density field obtained from large-eddy simulations. Important issues such as Reynolds number dependence of OPD, contributions from different flow regions and flow scales to the wavefront aberrations, and the dependence on propagation direction, are examined. The numerical database is further used to simulate Malley probe and 2-D wavefront sensor measurements and investigate their differences in terms of OPDrms, correlation lengths, and the effects of aperture size and unsteady tilt removal. The similarities and differences in optical distortions caused by attached boundary layers and separated shear layers are also discussed.

8395-13, Session 3

Aero-optical jitter estimation using higher-order wavefronts

M. R. Whiteley, D. J. Goorskey, R. Drye, MZA Associates Corp. (United States)

Wavefront measurements from wind tunnel or flight testing of an optical system are affected by jitter sources due to the measurement platform, system vibrations, or aero-mechanical buffeting. Depending on the nature of the testing, the wavefront jitter will be a composite of several effects, one of which is the aero-optical jitter; i.e., the wavefront tilt due to random air density fluctuations only. In order to isolate only the aero-optical jitter component from recent testing, we have developed an estimation technique which uses only higher-order wavefront measurements to determine the jitter. Because these higher-order measurements are unaffected by other jitter sources in the system, they can be used regardless of the additional sources of jitter in the test configuration. By analogy with work done previously with free-

stream turbulence, we have developed a minimum mean-square error (MMSE) estimator using higher-order wavefront modes to compute the current-frame tilt components through a linear operation. The estimator is determined from computational fluid dynamics (CFD) evaluation of aero-optical disturbances, but does not depend on the strength of such disturbances. We apply of this estimation technique to current wavefront data and provide characterizations of the aero-optical jitter component as compared with the full jitter disturbance.

8395-14, Session 4

Polarization gratings for nonmechanical beam steering applications

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Over the last few years, Boulder Nonlinear Systems (BNS) and North Carolina State University (NCSU) have developed a new beam steering technique that uses a stack of thin liquid crystal polarization gratings (LCPGs) to efficiently and non-mechanically steer a beam over a large field-of-regard (FOR) in discrete steps. This technology has been successfully transferred to BNS through an exclusive license agreement, and a facility has been completed to enable commercial production of these devices. This paper describes the capabilities enabled by both the LCPGs and the successful transfer of this technology.

8395-15, Session 4

Progress on large-area polarization grating fabrication

J. Kim, R. K. Komanduri, Y. Li, M. N. Miskiewicz, M. J. Escuti, North Carolina State Univ. (United States)

Over the last several years, we have pioneered liquid crystal polarization gratings (PGs), in both switchable and polymer versions. We also introduced their use in many applications, including nonmechanical laser beam steering that employs a stack of PGs as polarization-sensitive diffractive beam splitters with high efficiency. Until now, we and others have typically used a well-known polarization holography configuration to expose the PGs interference pattern with diameters in the range of 1-2 inches. In this paper, we discuss several alternative fabrication techniques to make larger PG samples (i.e., 6 inch diameter or more). We evaluate the various holography setups with collimated/diverging and coherent/partially-coherent recording beams. We also demonstrate large area polymer PG samples, and present detailed characterization including grating period uniformity, diffraction spectra, and output beam wavefront over the whole sample area.

8395-16, Session 4

Laboratory testing of a curved deformable mirror

M. T. Jacoby, M. T. Hunwardsen, R. H. Brigham, R. F. Pollock, C. Austrheim-Smith, C. C. Chen, Optical Physics Co. (United States)

Optical Physics Company (OPC) has manufactured a 10 cm diameter, 6x6 actuator pathfinder Deformable Primary Mirror (DPM) with 16.7 x 16.7 mm spacing, >13 microns stroke, 20 kHz update rate, 33% central obscuration and no guard rings under HEL-JTO funding. The same technology can be used to manufacture a deformable secondary mirror without an obscuration. The piston-tip-tilt (P-T-P) design enables precise, deterministic control of the subapertures as opposed to interpolative control so that inner and outer guard rings are not required. With no guard rings an optical designer can design a primary mirror for an HEL system without clear aperture constraints. P-T-P design is equivalent to 2X as many piston-only segments in correcting atmospheric or boundary layer turbulence and allows full branch point correction capability. OPC will present the results of laboratory testing to demonstrate actuator stroke, P-T-P control with no guard rings, update rate and lambda/10 P-V HeNe surface figure when the DPM is “flattened”.

8395-17, Session 4

High-frame rate Shack Hartmann wavefront sensor based on flexible read-out technique for C-MOS image sensor

J. Suzuki, T. Ando, Mitsubishi Electric Corp. (Japan)

The Shack Hartmann wavefont sensor has recently had attention for attractive approach to detect wavefront error without optical interferometry. It has found powerful tools not only in astronomy and adaptive optics, but also in optical testing, laser beam analysis. The Shack-Hartmann sensor consists of a lenslet array and position-sensing detector which determines the focal spot position. A CCD camera has widely used for such a position sensing, however its frame rate did not meet for high speed application. A C-MOS image sensor is promising device for high-speed Shack Hartmann wavefront sensor because of its higher read out speed than that of CCD, however, the frame rate is still limited up to one kHz on commercial off the shelf C-MOS image sensor. In order to overcome this limit, we adopted the flexible read out technique on C-MOS image sensor, which makes it possible to reduce not only the amount of Hartmann spot but also image size. In the preliminary experiments, we have successfully obtained 10x10-Hartmann diagram with a rate of 4kHz, leading to a high-frame rate wavefront sensor.

8395-18, Session 4

Refractive beam shaping optics to improve operation of spatial light modulators

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Inhomogeneity of intensity profile in techniques with illumination of SLM by laser beams leads to not efficient using of the SLM capabilities or complexity of algorithms to control these SLM. For example the typical Gaussian intensity distribution has peak intensity in the centre of a beam, and to prevent damaging the SLM it is necessary to reduce power of entire laser beam. In laser techniques like Computer Generated Holography (CGH) the not uniform intensity profile leads to essential increasing the complexity of mathematical models or makes some techniques of digital holography unrealizable. To overcome these drawbacks it is suggested to apply with SLM the refractive field mapping beam shapers providing high flexibility in building various optical setups due to their unique features: almost lossless intensity profile transformation from Gaussian to flattop, saving of the beam consistency, low output beam divergence and flatness of wavefront, extended depth of field, capability to adapt to real intensity profiles of TEM00 and multimode laser sources. Applications include CGH, holographic projection processing applications, holographic lithography, optical trapping and laser illumination in confocal microscopes. With a collimated flattop beam provided by refractive field mappers these techniques become easier to use, more effective and reliable in operation.

This paper will describe some design basics of refractive beam shapers of the field mapping type, with emphasis on the features important for applications with SLMs. There will be presented comparative results of applying the refractive beam shapers in systems of holographic lithography and other techniques.

8395-19, Session 4

Next-generation inductive transducers for position measurement

M. A. Howard, Zettlex UK Ltd. (United Kingdom)

Position transducers are a critical element in many pointing, tracking & acquisition systems. There are many types of position transducer, the most common are optical encoders and (traditional)inductive devices such as resolvers. Optical encoders offer high measurement performance but are delicate and unreliable in harsh environments. Traditional inductive devices are very robust but lack measurement performance and are too heavy or bulky for many applications.

Traditional inductive devices are based on the transformer principles first discovered by Michael Faraday in 1835. They use 3D wire constructions - usually in the form of precision wound spools of copper wire. Measurement accuracy is determined by the (in)accuracy with which wire can be wound on a spool. This basic technique means that they are also difficult and expensive to make - especially for the high accuracy applications often required by security and defence sectors.

Next generation inductive devices use similar basic physics but instead of wire wound constructions they use conductive arrays, printed on to lightweight flexible substrates or even on to the mechanical parts of the host equipment (such as a gimbal, antenna or lens systems). When such constructions are combined with the latest embedded software and micro-electronics they offer high measurement performance and robust operation without the bulk, weight and cost of traditional devices.

This paper examines the strengths and weaknesses of various approaches and describes the physics behind next generation inductive transducers. It describes the principles of operation, construction techniques, likely measurement performance and application areas.

8395-20, Session 4

Geo-pointing and geo-locating line-of-sight kinematics and control techniques

J. M. Hilkert, Alpha-Theta Technologies (United States)

A common requirement in electro-optical surveillance, target acquisition systems and other commercial and scientific applications is to point at or scan an object with fixed known coordinates from a moving vehicle without the use of automatic or manual target tracking. This paper reviews the basic kinematic algorithms required to derive the gimbal angles and rates necessary to accomplish this objective, commonly referred to as “Geo-Pointing”. The inverse of Geo-Pointing is “Geo-Locating”, in which case the coordinates of a tracked object of interest are derived from the measured coordinates and attitude of the moving host vehicle and the line-of-sight gimbal angles. The kinematic algorithms required to Geo-Locate a target are also addressed for both the case in which the range to the target is available from, for example a laser range finder, and the somewhat more difficult case in which range is not available. Several variations of each of the above line-of-sight control modes are presented along with various implementation techniques and issues. While the general algorithms developed are applicable to any gimbal configuration, the common two-axis AZ / EL configuration is used as an example to illustrate the techniques.

8395-21, Session 4

Two-port internal model control for gyro-stabilized platform of electro-optical tracking system

Y. X. Xia, Q. L. Bao, Z. J. Li, Q. Wu, Institute of Optics and Electronics (China)

Line-of-sight stabilized system, which can be used to isolate the vibration of the moving bed and the disturbance of environment, is the most important part of an electro-optical tracking system. The steady precision and robustness are the key issues of recent researches. In this paper, a novel control approach so called 2-Port Internal Model Control (2-PIMC) for line-of-sight stabilized system is proposed. By adding a parallel feedback control loop on the basis of Internal Model Control (IMC), the 2-PIMC method can improve the stabilized precision while it also has strong robustness as the IMC. The robustness and the static error of 2-PIMC method were subsequently analyzed. Based on this novel method, Simulation and experiment are both carried out for a gyro stabilized platform of electro-optical tracking system. The experiments include a shaking table which can generate disturbance as the moving bed and a gyro stabilized platform which is mounted on the shaking table. Both the Simulated and experimental result indicated that the gyro stabilized platform using 2-PIMC method is accurate and effective. Comparing with PID control, the following error and disturbance restraining error were both greatly improved at low-frequency and mid-frequency by the 2-PIMC method proposed. The improvement of precision is more than 10dB at 4Hz. In addition, the 2-PIMC method doesn’t need any extra sensors for the platform and it’s easy for parameters regulation. It can be concluded that the2-PIMC method is a new approach for the high-performance gyro stabilized platform and might have broad application prospect.

8395-22, Session 5

USAF/Navy high-energy laser (HEL) systems: HEL-generated extinction of multispectral algorithm efficiencies during missile staging and early midcourse (ascent cases: PRC DF-31; GHADR 110)

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This comprises continued research addressing missile exhaust plume ionization adverse effects; such HEL ionization processes occurring as a function of altitude, exhaust and attitude control systems (DACS) plume expansion and reverse (Prandtl-Meyer) exhaust flows. It is demonstrated that these processes adversely affect the USAF/Navy multi-wavelength Discriminating Interceptor Technology Program (DIT)’s infrared and millimeter wave fused system. Target case study are the PRC DONG FENG 31 solid propellant systems, with applications to Iranian GHADR 110 MRBM (extended). Boost-phase and Early Midcourse (Ascent) missile exhaust and DACS plumes have been shown to generate a variety of very challenging plasma and electromagnetic HEL extinction effects. As a result the HEL fluence (energy in the bucket), decreases significantly in intensity. The overall engagement event results in HEL plasma-plume interactions (absorption-scattering) reducing returned energy on the infrared focal plane for HEL designators; and reduced HEL fluence-on-target. Video analysis included 10 July 2011 Chinese launch of DF-31, from which exhaust plume spatial and temporal characteristics were obtained. Such missile discriminates included expanded and reversed exhaust plumes, which are shown to generate very severe propagation extinction within the Prandtl-Meyer and HEL engagement regimes. This further results in inadequate automatic target recognition and effective pattern reference libraries. Unique HEL plasma-plume interactions occur when asymmetric flows interact with high-energy laser transmissions through missile Prandtl-Meyer reverse flow regions and high angle-of-attack regimes. Angle-of-attack asymmetric radiance increases result from increased trajectory energy maintenance maneuvers by boost-phase missile exhaust, including dedicated energy maneuvering and evasive thrust vectoring. Intense exhaust plume/atmospheric ram interactions result in high critical ionization levels within the missile chemical excitation regions which then interact with HEL Beam Illuminator and Tracking Illuminator Lasers, as well as the primary kill beam. Cumulatively these processes challenge ATDCI algorithms, which rely on spatially limited ATDCI-ATR (automatic target recognition) referencing systems. Current ATR algorithms do not account for these negative plasma-plasma interactions of asymmetric, angle-of-attack rocket exhausts and high-energy laser plasma interactions. ADTCI-ATR libraries must include sufficiently robust exhaust plasma data to insure high probability of successful target intercepts. Finally, these libraries must include angle-of-attack and afterburning characterizations for the new boost-phase Iranian: GHADR-110, PRC DF-31, and North Korean TAEPODONG-2/III ICBM missile systems which are in production.

8395-23, Session 5

Determination of feature generation methods for PTZ camera object tracking

D. D. Doyle, Air Force Institute of Technology (United States)

Object detection and tracking using computer vision (CV) techniques have been widely applied to sensor fusion applications. Recent work focuses on improving algorithms, workload distribution, and information fusion to speed up performance and extend these advances into new applications. As the needs for military application of real-time tracking systems increase and become more complex, more effort is needed to improve fusion and CV techniques to actively track and control dynamic systems. Some specific applications include the use of metrology systems for tracking and measuring micro air vehicles (MAVs) during the research and development phase, autonomous navigation systems for controlling MAVs in operational settings, and using MAVs as surveillance systems for capturing and interpreting enemy intent. This paper presents a comparison test between several tracking algorithms on the task of tracking a moving object using a pan/tilt/zoom (PTZ) camera, which is necessary for all of the examples presented. The feature generation algorithms compared include Scale-Invariant Feature Transform (SIFT), Speeded Up Robust Features (SURF), Mixture of Gaussians (MoG) background subtraction, Lucas-Kanade optical flow, and Farneback optical flow. The matching algorithm used with SIFT and SURF is the Fast Library for Approximate Nearest Neighbors (FLANN). Comparison testing uses a sequence of images of a rotating and translating target in both a static and dynamic background using a PTZ camera in order to capture the moving object. The most applicable algorithm is determined based upon execution time, memory requirements, and match accuracy based upon object center of mass.

8395-24, Session 5

Development and testing of the advanced integrated multisensor system (AIMS) for active and passive tracking and imaging

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The development, integration, assembly and testing of the Advanced Integrated Multi-sensor System (AIMS) demonstrated its applicability as a space surveillance system. AIMS visible, near-IR, mid and long-wave (MWIR and LWIR) sensors combined with an active laser to simultaneously track a remote target. Using a set of signals detected by the imaging and non-imaging sensors it locked on and continuously tracked flight trajectory. The AIMS shared optical train simplified issues associated with spatial correlation and temporal synchronization of sensor array information. This enabled effective sensor data fusion and allowed more effective target identification, characterization and discrimination.

8395-25, Session 5

Peak-seeking control techniques for stabilized antenna tracking

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Classic control approaches for stabilized, tracking antenna systems depend on an inner stabilization loop (based on gyroscope velocity feedback) with an outer tracking loop (based on signal strength feedback). The tracker only has a signal strength measurement - no absolute information about the position of the target relative to the line-of-sight of the antenna is available. The control system must actively “scan” or “dither” the antenna line-of-sight and then observe signal strength to estimate the relative position of the target. Here we apply peak-seeking techniques from other fields to the problem of antenna stabilization and tracking in search of novel control strategies.

We present block diagrams of significantly different architectures. We address the fundamental trade-off between dithering (or scanning) more such that observability of relative position is increased, but at the same time mean pointing error is also increased because of dither induced jitter. We present different simple Kalman filter formulations for estimating positions or signal function gradients, taking architectures from other fields and applying them to this problem. We show that naturally occurring line-of-sight motion (unrejected disturbances) can be used for relative position estimation rather than actively adding dither. Some example simulation results are presented.

8395-26, Session 5

Polynomial fitting adaptive Kalman filter tracking and choice of correlation coefficient

K. Ausfeld, Z. Ninkov, Rochester Institute of Technology (United States); J. D. Newman, P. P. K. Lee, ITT Exelis Inc. (United States); G. J. Gosian, ITT Corp. (United States)

Kalman filters have been used as a robust method for object location prediction in various tracking algorithms for nearly a decade. More recently, adaptive and extended Kalman filters have been employed, making predictions even more reliable. The presented addition to this trend is the employment of a polynomial fit to the history of object locations, using the adaptive Kalman filter framework. This allows the linear state model of the adaptive Kalman filter to predict nonlinear motion, making tracking more robust. This modified filter will be used in conjunction with the Mean Shift algorithm as the measurement step. Another important consideration when using a Kalman filter in this maner will be which correlation coefficient is used. The Pearson product-moment correlation coefficient is shown to provide more robust tracking when compared to the Bhattacharyya coefficient when objects have either low resolution or are unresolved.

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8396-01, Session 1

Semantics for airborne video imagery ontology

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A prototype Airborne Video Collection Ontology has been developed for video imagery intelligence: VideoIMINT. The objectives of this effort include, 1) Build a semantic hierarchy to encompass the whole of airborne collection systems such as video image content, and video collection metadata semantically related to platforms, sensors, collection operations and performance; 2) Explore the classes and properties necessary to enable logically formal relationships among these system components; 3) Demonstrate automatically derived and populated classes from morphological feature extraction of video imagery content; 4) Integrate these content and operational classes along with metadata classes to identify selected video segments for display in an integrated viewer, and 5) populate an information fusion framework while providing data storage management.

8396-02, Session 1

Pipelined hardware design for infrared image processing

B. Fortener, Univ. of Dayton Research Institute (United States); E. Balster, Univ. of Dayton (United States); W. Turri, Univ. of Dayton Research Institute (United States)

Infrared, wide-area surveillance (IR-WAS) data poses a problem to those looking for real-time monitoring and exploitation. IR-WAS data is typically captured at a bit-depth of 14 bits or more, greater than that typically captured in grayscale, electro-optical (EO) cameras. Furthermore, a greater amount of processing is needed in order to make it visually useful and exploitable by image analysts. Typically, non-uniformity correction (NUC), bad pixel detection (BPD), and bad pixel replacement (BPR) algorithms are applied to alleviate problems caused by sensor inconsistencies. Other algorithms are more for utility: dynamic range compression (DRC) is used to modify the data for visual display, unsharp masking (USM) is used to highlight high spatial-frequency regions and to deblur the imagery, and image compression algorithms such as JPEG2000 are used to compress the imagery so that it can be cheaply stored. With today's sensors being capable of capturing very large images at a relatively high framerate, the bottleneck becomes the processing of the data at a rate that can keep up with IR-WAS cameras. A pipelining approach can be taken to achieve the throughput needed in a wide area surveillance system. With a pipelined architecture implemented on an FPGA, CPU time can be freed up for use on tasks more suited to the host CPU, and more importantly, latency and processing delay can be greatly reduced. This paper details a pipelined hardware design for an infrared image processing chain that is highly scalable and suited to meet the demands of IR-WAS data systems.

8396-03, Session 1

Feature fusion using ranking for object tracking in aerial imagery

S. Candemir, F. Bunyak, K. Palaniappan, Univ. of Missouri-Columbia (United States); G. Seetharaman, Air Force Research Lab. (United States)

Aerial wide area monitoring and tracking using multi-camera arrays poses unique challenges due to low frame rate sampling, low resolution targets, limited image contrast, static and dynamic parallax occlusions compared to standard full motion video motion analysis. We have developed a low frame rate tracking system using fusion of a rich set of color, texture and shape features. This large feature set enables adaptation of the tracker to dynamic environment changes and target appearance variabilities. However, computational cost of large feature sets makes them unfeasible for real-time tracking. Moreover if not properly fused, low quality features may even reduce tracking performance.

This paper presents a framework for dynamic feature evaluation and fusion. First, we present a set of low resolution descriptors suitable for small sized objects in aerial video. Seven multiview feature sets describing texture, shape, intensity and color combinations are described.Then, we provide a feature selection procedure based on a target-background discrimination power where features are scored based on a two-class variance ratio (VR) approach. A subset of the K most discriminative features are selected for further processing and fusion. Finally, we compute target match probability maps for selected features by comparing target descriptors to local search window using a sliding window approach. Individual feature probability maps are fused into a joint probability map to be used in target localization using VR weighted sums.

We quantitatively measure the performance of the described system with respect to ground-truth detections and tracks using our feature and tracker evaluation test-bed that incorporates various experiments and performance metrics. The proposed feature ranking and fusion approach decreases the computation time and increases localization accuracy by reducing multimodal effects introduced by low quality features and background distractors. Adaptive scoring increases robustness of the tracker for dynamically changing environments.

8396-04, Session 1

Developments for a harmonized metadata model for improving cross-community geo-related search and retrieval

D. Böker, P. Harant, P. Watzka, A. Weigel, IABG mbH (Germany)

Some data like still images and motion imagery are limited in use if no ancillary metadata is available. This metadata can help to interpret such data by including descriptions of their content and context. The geospatial position, where the data was collected or an object detected therein is located, and an object classification, are examples of such content and context descriptions. But metadata can also address management aspects for data dissemination. Thus, users of the data, their roles and rights for data access and manipulation, as well as information about dissemination paths and security classifications can be stored in metadata. In consequence, metadata are valuable inputs for data handling, especially in net-centric environments. From net-centric environments incorporating various sensor assets and operational users of information, an issue arises in the use of harmonized metadata: Since there are different communities of interests (COIs) trying to work together, but the data handling between those COIs differs, metadata of those COIs differs, too. The goal of the approach reported herein is to harmonize metadata between selected COIs by analyzing use cases of metadata in those COIs, deriving requirements on metadata for these use cases, comparing metadata models from the COIs, and developing a common core metadata model as a superset of the COIs' metadata models. Current efforts and results of this metadata harmonization are reported in this article.

8396-05, Session 1

Interactive target tracking for persistent wide-area surveillance

I. Ersoy, K. Palaniappan, Univ. of Missouri-Columbia (United States); G. Seetharaman, Air Force Research Lab. (United States); R. M. Rao, U.S. Army Research Lab. (United States)

Wide area persistent surveillance is a newly emerging technology that provides continuous coverage of several square miles with a temporal sampling of one to two frames per second. Aircraft-based multiple camera systems provide live, high resolution images (16K by 16K pixels) that are collected, georegistered and projected on board for a single, stabilized view with real-time replay capability. Storing, viewing and analyzing these images for purposes of change detection, active surveillance or scene forensics provides unique challenges for computer vision algorithms such as very large data size (terabytes), registration and projection errors across multiple cameras as well as registration errors due to IMU sensor noise, very low frame rate, changing viewpoint, occlusions and strong parallax effects due to flight pattern. Existing approaches for target tracking usually require smooth motion and high frame rates or a stable background model to achieve reasonable performance. We developed an algorithm that overcomes these challenges by combining several approaches such as local stabilization and an adaptive set of target descriptors that can robustly represent and detect targets through changing visual conditions. The developed algorithm does not require smooth motion, high frame rate or a background model in order to detect moving or stationary targets. It can perform tracking in an online, real-time fashion in order to provide the user with interactive target tracking capability. The developed algrithm is seamlessly integrated with an interactive visualization tool and its performance is demonstrated on real data obtained from an operational platform.

8396-06, Session 1

A geometry based image search engine for advanced RADARSAT-1/2 GIS applications

V. Kotamraju, B. Rabus, MacDonald, Dettwiler and Associates Ltd. (Canada)

Space-borne Synthetic Aperture Radar (SAR) sensors, such as RADARSAT-1 and -2, enable a multitude of defense and security applications owing to their unique capabilities of cloud penetration, day/night imaging and multi-polarization imaging. As a result, advanced SAR image time series exploitation techniques such as Interferometric SAR (InSAR) and Radargrammetry are now routinely used in applications such as underground tunnel monitoring, infrastructure monitoring and DEM generation. Imaging geometry, as determined by the satellite orbit and imaged terrain, plays a critical role in the success of such techniques.

This paper describes the algorithms, architecture and the current status of development of a geometry-based search engine that allows the search and visualization of archived and future RADARSAT-1/2 images appropriate for a variety of advanced SAR techniques and applications. Key features of the search engine include (a) Interactive GIS-based visualization of the search results; (b) A client-server architecture for online access that combines up-to-date searches of the archive images with planning of future acquisitions; (c) A technique-specific search mode, wherein an expert user explicitly sets search parameters to find appropriate images for advanced SAR techniques such as PolSAR, InSAR and Radargrammetry, (d) An application-specific search mode, wherein all search parameters implicitly default to preset values according to the application of choice such as tunnel monitoring, DEM generation, deformation mapping (for urban subsidence, landslides and carbon sequestration), ice classification and ship detection; (f) Accurate baseline calculations for InSAR searches, and, optimum beam configuration for Radargrammetric searches; (g) Simulated quick look images and technique-specific sensitivity maps.

8396-07, Session 1

KOLAM: an extensible cross-platform architecture for visualization and tracking in wide-area motion imagery

J. Fraser, A. Haridas, Univ. of Missouri-Columbia (United States); G. Seetharaman, Air Force Research Lab. (United States); K. Palaniappan, Univ. of Missouri-Columbia (United States)

KOLAM is an interoperable, scalable and extensible framework for visualization and target tracking in high-resolution, high throughput wide format video also known as wide-area motion imagery (WAMI). KOLAM was originally developed for the interactive visualization of extremely large geospatial imagery of varying spatial and spectral resolution. KOLAM is platform, operating system and GPU hardware independent, and supports embedded datasets scalable from hundreds of gigabytes to petabytes in size on clusters, workstations, desktops and mobile computers. In addition to rapid roam, a zoom and hyper-jump spatial operation, KOLAM supports an arbitrary number of simultaneously viewable embedded layers or channels, interactive color map and histogram enhancement, spherical projection and terrain maps. The KOLAM software architecture was extended to support airborne wide-area motion imagery by organizing very large format video frames as a temporal sequencing of pyramid data structures. The current version of KOLAM supports animation, target tracking and trajectory visualization; the latter comprising the outputs of both tracker algorithm execution and ground-truth generation. Among the current critical needs for working with WAMI is an assisted tracking and visualization tool that allows analysts to rapidly track multiple targets, review tracking results and apply visual analytic tools on the generated track data. KOLAM provides one-click manual tracking, which is combined with multiple automated tracking algorithms to assist the analyst and increase human effectiveness.

8396-08, Session 1

UHF-SAR and lidar fusion for precise buried object detection

A. Shaw, Wright State Univ. (United States)

The UHF band in SAR has foliage penetration and limited ground penetration capability, while LIDAR can provide both elevation and intensity records to create 3-D representation of objects on the terrain. In this paper, we integrate the complementary strengths of these two different classes of sensors to locate buried objects with improved precision. The main idea is to exploit the LIDAR elevation information at the UHF-SAR detections and eliminate the above-ground false-alarms in the UHF-SAR domain, isolating the buried IEDs. In this paper, we demonstrate definitive proof-of concept validation of same-day/single-pass buried object detection capability using single-pass SAR Anomaly Detection with LIDAR integration. We also demonstrate significant performance improvement with 2-pass SAR Change detection with LIDAR integration. The proposed SAR-LIDAR integration strategy is shown to detect emplaced buried objects with an order of magnitude improvement in detection performance, i.e., achieve higher PD at lower PFA when compared with SAR-only performance. The proof-of-concept research was conducted under an Air Force SBIR Phase I (Topic: AF093-139), and is demonstrated on simultaneous multisensor UHF-SAR/LIDAR data collected under JIEDDO's HALITE-1 program.

8396-09, Session 1

Autonomous cross-correlation of optical MTI for live inspection and tracking

J. A. Edelberg, B. J. Daniel, M. L. Wilson, J. G. Howard, J. N. Lee, U.S. Naval Research Lab. (United States); M. Jensen, T. Johnson, S. A. Anderson, C. Meadows, Space Dynamics Lab. (United States); S. Frawley, Smart Logic, Inc. (United States)

Autonomous networked sensor collaboration is an ongoing research goal across academia, industry and the Department of Defense. Through support from the Office of Naval Research, the Naval Research Laboratory (NRL) recently demonstrated use of a mid-wave infrared (MWIR) wide area airborne surveillance (WAAS) system to autonomously cue and drive an EO/IR inspection and verification system. The WAAS imagery is collected using NRL's 16 Mpix MWIR Nighttime Wide-Area

Persistent Surveillance Sensor (N-WAPSS) and is processed in real-time to generate moving target indication (MTI) tracks for all moving vehicles in a 1 km square area. These MTI tracks are then provided to a user for highlighting and inspection. The user can promote up to 6 live MTI tracks to the EyePod electro-optic (EO) / long-wave infrared (LWIR) inspection sensor. EyePod was developed at the Space Dynamics Laboratory and is capable of managing multiple simultaneous imagery requests and then parsing these requests to collect and output imager sets consistent with all active targeting requests. For this demonstration, up to 4 live MTI tracks were simultaneously promoted to EyePod. EyePod then sequentially polled each track head and provided those track inspection updates to the user's screener display set. The screener then parsed out the simultaneous streams to provide the user with individual updated windows for each of the MTI tracks. Automatic detection algorithms and overall system performance metrics will be presented along with flight results from the combined WAAS/inspection testing.

8396-10, Session 1

Optimizing sensor placement using predictive geospatial analytics, the physical environment, and surveillance constraints

G. Schmidt, B. Witham, J. Valore, B. Holland, J. Dalton, GeoEye Analytics (United States)

Military, police, and industrial surveillance operations could definitely benefit from having sensors deployed in configurations that maximize collection capability. We describe a surveillance planning approach that optimizes sensor placements to collect information about targets of interest by using information from predictive geospatial analytics, the physical environment, and surveillance constraints. We designed a tool that accounts for multiple sensor aspects-collection footprints, groupings, and characteristics; multiple optimization objectives-surveillance requirements and predicted threats; and multiple constraints-sensing, physical environment (including terrain), and geographic mission constraints. The tool uses a discrete grid model to keep track of geographic sensing objectives and constraints, and from these, estimate probabilities for collection containment and detection. We devised an evolutionary algorithm and polynomial time approximation schemes (PTAS) to optimize the tool variables above to generate the positions and aspect for a network of sensors. We also designed algorithms to coordinate a mixture of sensors with different competing objectives, competing constraints, couplings, and proximity constraints. The surveillance planning approach tool and algorithms are described in this paper.

8396-11, Session 1

Cyberspace information models for integrated data harvesting, representation, and exploitation

R. B. Porter, L. Collins, J. Powell, R. Rivenburgh, Los Alamos National Lab. (United States)

Geospatial information systems provide a unique frame of reference to bring together a large and diverse set of data from a variety of sources. However, automating this process remains a challenge since data (particularly from sensors) is error prone and ambiguous, and analysis and visualization tools typical expect clean (or exact) data. In this paper we describe an integrated approach to data harvesting, representation and exploitation that can help address some of these challenges. We propose a hierarchy of models that include: 1) A Cyber-space Information Model that characterizes the inputs to the GIS (e.g. Map Servers, Social Networks, Open Source Center) , 2) A Domain-space Information Model that characterizes the geospatial entities relevant to an application (e.g. Venues, Actors and Activities) and 3) A Problem-space Information Model that characterizes how these entities form patterns of interest (e.g. multi-vehicle meetings). We use Markov Logic Networks to representation the combination of deterministic and probabilistic dependencies found within the hierarchy, and demonstrate how the hierarchy improves system-level performance measures using synthetically generated data. Specifically, we show that the cyber-space information model can help improve geospatial entity resolution which is more typically applied just within the domain model.

8396-12, Session 2

Using GIS databases for simulated nightlight imagery

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Proposed is a new technique for simulating nighttime scenes with realistic nightlight spectra. Estimating urban development is a common task for satellite platforms that image the Earth at night. Upwelling radiance from streetlights, buildings, and other sources have been shown to directly relate to the level of urban development though power laws. Zipf's Power Law approximately describes this relationship for a broad range of cities. Here, Zipf's Law is applied to the less common, inverse task of estimating the spectral upwelling radiance of nightlights using GIS data relating to development.

Data indicative of buildup may be the type and density of streets and buildings. The Open Street Map (OSM) project consists of a rich worldwide GIS database of such data. These GIS data are used to generate nightlight scenes, given certain assumptions based on geographic location. An example assumption is that highways in North America are lit using sodium-vapor lamps, while city streets are lit with mercury-vapor lamps. Spectra and spatial definitions of different light sources are defined using these assumptions.

Given the OSM data and informed assumptions, synthetic scenes may be constructed. In theory, these synthetic scenes which exemplify Zipf's should be reasonable approximations of real scenes. Accuracy of simulated imagery is partially determinable through comparison with real imagery from existing sensors such as DMSP. Validation is subject to the spectral, radiometric, and spatial limitations of the various systems. Synthetic nightlight generation adds significant value to the ability to generate realistic nighttime imagery, particularly on large scales.

8396-13, Session 2

NATO STANAG 4586 Complaint Steerable Video Chips from JPEG 2000 Large Volume Data Sets

B. V. Brower, R. Shuler, T. Looney, B. Raymond, M. F. Pellechia, ITT Exelis Inc. (United States)

In this paper we describe an extension of a published approach to the real-time generation and dissemination of steerable video-format chips from large volume motion imagery streams. The proposed large volume motion imagery architecture maintains all the benefits of incorporating a JPEG 2000 archival format, while also boasting the ability to disseminate regions-of-interest (ROI) and low resolution overviews to an even greater number of simultaneous clients. We describe the approach and test results associated with extending this architecture to include an implementation of NATO STANAG 4586, Level 3 controls, used to modify ROI windows delivering standards compliant Full Motion Video (FMV). Compliance to STANAG 4586 standards provides an interface profile definition that ensures air-ground data-link and command/control messaging for Unmanned Aircraft Systems (UAS). Traditionally, STANAG 4586 interfaces are applied to full-motion video sensors. This paper provides implementation guidance, along with measured results where NATO STANAG 4586 interfaces have been applied to large frame motion imagery sensor architectures. Our approach employs JPEG 2000 (J2K) compression and disseminates near-real-time transcoded MPEG-2 and H.264 over MPEG transport streams in compliance with the guidelines established by the National Geospatial-Intelligence Agency (NGA) Motion

Imagery Standards Board (MISB). Finally, our study will compare/contrast a STANAG 4586-based approach to streaming video over varying bandwidth communication channels to an alternate approach using JPEG 2000 Interactive Protocol (JPIP).

8396-14, Session 2

Geospatial Processing of Registered H.264 Data

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The H.264 protocol for high resolution video offers several enhancements which can be leveraged for the selective tracking and focused resolution of disjoint macro-blocks of the frame sequence such that a smooth degradation of context is achieved at significant compression rates. We demonstrate the near real time temporal and spatial foveation of the video stream. Tracking results produced by spatial statistics of the geo-registered motion vectors of the H.264 frames are useful for change detection and background discrimination as well as temporal foveation. Finally, we discuss the online analytical processing of the spatial database of full motion video through use of the automatically generated geospatial statistical descriptor metadata.

8396-16, Session 2

The hybrid approach for large-scale network access and querying

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Geo-spatially querying and analyzing large high-resolution spatial networks is critical to most of defense and security applications to support military intelligence. However, the majority of existing solutions either store the entire network in memory, which is not scalable, or adopt a disk-based network representation (i.e., SNDB), where routing and spatial queries may incur high I/O overhead and hence is inefficient. In this paper, we present a flexible architecture for large spatial network storage using grids. In particular, this hybrid approach preserves network connectivity and proximity within each partition for local search while enabling heuristics to minimize the I/O overhead for queries of large scale. We further develop efficient algorithms to process spatial queries based on this hybrid storage schema.

8396-17, Session 2

Standards support for activity based intelligence

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The dramatic success and proliferation of video and wide area persistent surveillance systems is bringing about a crisis in our ability to effectively exploit the vast volume of new ISR imagery. Activity-Based Intelligence (ABI) is envisioned as the cornerstone of the defense and intelligence communities' approach to this problem. In ABI, we narrow our focus of attention, within the vast data collected by Intelligence, Surveillance, and Reconnaissance (ISR) systems, to just identifying and analyzing activities of interest within the collection. The Motion Imagery Standards Board is engaged in multiple initiatives designed to help support ABI. This paper describes a suite of approaches based on previous MISB work on a standards-based "micro-architecture" for tracking. It focuses on ABI in the context of automated tracker results, and shows how the MISB tracker formulation helps to formalize important components of the ABI problem. The key result is a proposed grammar-based formalism for the reporting of activities within a stream of FMV or wide-area surveillance data, i.e., for an extensible descriptive language for ABI. We show how this language can induce an ABI "layer" in tracking systems as it defines advanced query and alerting services. This will allow a standard set of interfaces for ABI support technology to be built without any requirement to standardize the algorithms that implement the automated extraction of activities from motion imagery.

8396-18, Session 3

Uncertainty handling in geospatial data

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The meaning of the term conflation varies considerably among different user domains. It can be broadly defined as a blending or merging of different data sets that overlap, from which the (new) whole is of greater value than the individual inputs. Input data sets may differ in scale, fidelity, accuracy, format, and structure. The fundamental processes of conflation are 1) find correspondence features between input data sets; 2) determine an optimal functional mapping from the correspondence features; and 3) transfer information between input data sets that facilitate methods of discovery, clarification, augmentation, or update; and 4) estimate uncertainty in the information transfer process. Uncertainty estimation process can often be the most challenging, and consequently omitted process. The purpose of this paper is to provide insights and recommendations for dealing with uncertainty analysis when conflating spatial data sets.

Conflation applied to spatial data generally considers as input, feature (vector) and gridded (raster) data. Conflation processes also consider non-spatial information, e.g., use of textual metadata or 'attributes' as a source of information for correspondence or transfer. In this sense, conflation may be viewed as a form of generalized data registration. For example, methods of image-to-image 'registration' that are mainly interested in transferring spatial information (e.g., coordinates) would represent a special case of data conflation.

In this paper, we demonstrate how traditional concepts of photogrammetric error propagation could be extended to the data conflation process for certain data sets. We also propose a strategy to develop data standards that incorporate provenance that can enable more rigorous uncertainty analysis when performing data conflation in general.

8396-19, Session 3

Addressing terrain masking in orbital reconnaissance

S. Mehta, Mercury Computer Systems, Inc. (United States)

Addressing Terrain Masking in Orbital Reconnaissance

By Sharad Mehta & Luke Cico, Mercury Computer Systems, Chelmsford, MA

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During aerial orbital reconnaissance, a sensor system is mounted on an airborne platform for imaging a region of interest on the ground for a period of time. The raw images need to be processed in real-time using onboard processing systems to generate and transmit image products to end-users. The latency between the image acquisition and delivery of actionable image information to the end-user is critical and needs to be minimized. Due to the fine resolution of the sensors and the large field-of-view, the volume and rate of data generated by these sensors is large. The images are taken at oblique angles and then stabilized and ortho-rectified for exploitation. The line-of-sight of the sensor is often interrupted by terrain features such as mountains or tall man-made structures. The process of ortho-rectification renders the areas hidden from the line-of sight of the sensor with spurious information. Strategies are needed to address the terrain masking of areas within the field-of-view of the sensor. This paper discusses the approach for addressing terrain masking during orbital reconnaissance in SWaP and memory constrained onboard real-time image processing systems.

8396-20, Session 3

Feature selection using SFFS for appearance-based vehicles tracking in wide-area imagery

M. Poostchi, F. Bunyak, K. Palaniappan, Univ. of Missouri-Columbia (United States)

Object tracking in video requires robustness to imaging conditions, environmental characteristics, sensor response and appearance variability.Current video tracking systems often employ a rich set of intensity, edge, texture, shape and object level features combined with descriptors for appearance modeling. The descriptors are used in conjunction with other cues such as motion, object class, and background clutter to detect the target and track it over time.This approach increases tracker robustness but is computationally expensive for realtime applications and localization accuracy can be affected by including lower quality features in the feature fusion or object classification process.This paper explores offline feature subset selection for video tracking to reduce the dimensionality of the feature space and discover a representative lower dimensional (non-projection) subspace for online tracking. Optimal feature subset selection is combinatorially intractable. We compare dynamic sequential floating forward search (SFFS) to sequential forward selection (SFS) - two standard approaches used in machine learning. Given an application specific evaluation function, the SFFS algorithm finds the best feature subset by considering the conditional inclusion and exclusion of the features. This is more flexible and powerful than the popular greedy SFS method which always adds to the feature set during each iteration of feature subset evaluation. Our feature subset evaluation system is independent of the full tracking environment and uses just the ground truth target locations. Likelihood maps for each feature are constructed using sliding window comparison methods between the target and ROI feature histograms. Local maxima in each feature likelihood map are sorted based on their (matching) likelihood. The rank of the local maxima corresponding to the target location is used as an effectiveness measure of a feature. Several likelihood fusion methods can be used to combine k feature likelihood maps into one joint likelihood map at each iteration.SFFS incrementally expands the number of features from one to N over N iterations. Each of the feature sets is evaluated over all the targets and frames to obtain an aggregate score. SFS was evaluated under the same conditions. Experiments show that the SFFS-based selection outperforms greedy selection and the use of offline SFFS selected features not only reduces time complexity, but also leads to better online tracking performance

8396-21, Session 3

Validate and update of 3D urban features using multisource fusion

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As forecast by the United Nations in May 2007, the population of the world transitioned from a rural to an urban demographic majority with more than half living in urban areas. Modern urban environments are complex 3-dimensional (3D) landscapes with 4-dimensional patterns of activity that challenge various traditional 1-dimensional and 2-dimensional sensors to accurately sample these man-made terrains. Depending on geographic location, data resulting from LIDAR, multi-spectral, electro-optical, thermal, ground-based static and mobile sensors may be available with multiple collects along with more traditional 2D GIS features. Reconciling differing data sources over time to correctly portray the dynamic urban landscape raises significant fusion and representational challenges particularly as higher levels of spatial resolution are available and expected by users. This paper presents a framework for integrating the imperfect answers of our differing sensors and data sources into a powerful representation of the complex urban environment. A case study is presented involving the integration of temporally diverse 2D, 2.5D and 3D spatial data sources over Kandahar, Afghanistan. In this case study we present a methodology for validating and augmenting 2D/2.5D urban feature and attribute data with LIDAR to produce validated 3D objects. We demonstrate that nearly 15% of buildings in Kandahar require understanding nearby vegetation before 3-D validation can be successful. We also address urban temporal change detection at the object level. Finally we address issues involved with increased sampling resolution since urban features are rarely simple cubes but involve TV dishes, rooftop walls, and domes among other things.

8396-22, Session 3

Vehicle orientation estimation for Radon transform-based voting in aerial imagery

R. V. Pelapur, F. Bunyak, K. Palaniappan, Univ. of Missouri-Columbia (United States)

Persistent vehicle tracking in airborne video has gained a lot of attention in the past few years. This involves a number of challenges particularly in cluttered environments including vehicle detection, filtering, prediction, pose estimation and association. Estimating the pose or orientation of a moving object can improve tracking accuracy by reducing the likelihood of false matches and providing additional constraints for filtering and prediction. Although vehicles are rigid or articulated objects they undergo significant appearance change and deformations due to the multi-camera optics and airborne viewing geometry between sensor and target. In this paper we propose an image based vehicle orientation estimation module that involves gradient enhancement, edge detection and linking, Radon transform-based voting and peak detection and correspondence analysis. Explicit orientation estimation is beneficial to explore since the majority of feature descriptors are designed to be rotationally invariant. Additionally, automatic orientation estimation can speed up manual ground-truth collection that is often necessary for validation and performance analysis as well as improve the quality of the manual tracks. The typical method of manual tracking involves marking only centroids since this is the simplest, or drawing and moving an axis-aligned bounding box drawn around the object of interest; general polygons are too time consuming to draw or correct on each frame. A good compromise is to use an oriented bounding box which takes vehicle geometry and pose into account. The proposed method is evaluated using intensity-based root mean squared error between the image and the aligned target after image warping, the angular error between the estimated and true orientation and the sensitivity of these metrics to absolute pose and change in motion direction of travel (stationary, linear versus turning). Initial results on the robustness of the proposed method for the more difficult cases of occlusions and shadows are presented.

8396-23, Session 3

Particle filter-based vehicle tracking using a nonlinear motion model

R. Viguier, K. Palaniappan, Univ. of Missouri-Columbia (United States); E. Duflos, P. M. Vanheeghe, École Centrale de Lille (France)

Tracking in wide area motion imagery faces many challenges including low resolution, multiple small-sized targets, low frame rate and complex backgrounds. Feature-based tracking techniques generate multiple peaks and have difficulty in distinguishing the target from distractors. Consequently, the wider the search area, the higher will be the number of false detections. It is therefore critical to use a refined motion model in order to eliminate spurious matches, reduce the size of the search region and at the same time estimate an accurate probability density of the predicted position to improve the target to track association. We introduce an orientation and magnitude based representation of the vehicle dynamics which leads to a non-linear motion model. We use a particle filter to handle both non linearity of the motion model and fusion with object feature likelihood maps within the search window that are often multi-modal. In the first step of particle filter prediction, we

randomly sample small changes in velocity orientation and magnitude. Then the probability map built from the appearance-based features is directly used as a likelihood estimatate to update particle weights. After resampling, the probability for a point to be chosen as the target location becomes proportional to the initial number of particles on it as much as the feature-based similarity with the target template. This approach shows promising results by reducing the false alarm rate and simultaneously reducing the size of the search window. The improved prediction provided by the particle filter-based probability density estimation compensates for the reduced reliability of feature-based histogram matching due to appearance changes, especially during turns and partial or full occlusions. Preliminary experiments using wide area motion imagery demonstrate that the particle filter combined with a non-linear motion model out-performs a Kalman filter-based prediction using a linear motion model.

8396-24, Session 3

Modeling spatial uncertainties in geospatial data fusion and mining

B. Kovalerchuk, Central Washington Univ. (United States); L. I. Perlovsky, Air Force Research Lab. (United States) and Harvard Univ. (United States)

Geospatial data analysis relies on Spatial Data Fusion and Mining (SDFM), which heavily depend on topology and geometry of spatial objects. Capturing and representing geometric characteristics such as orientation, shape, proximity, similarity, and their measurement are of the highest interest in SDFM. Representation of uncertain and dynamically changing topological structure of spatial objects including social and communication networks, roads and waterways under the influence of noise, obstacles, temporary loss of communication and other factors is another challenge. Spatial distribution of the dynamic network is a complex and dynamic mixture of its topology and geometry.

Historically, separation of topology and geometry in mathematics was motivated by the need to separate the invariant part of the spatial distribution (topology) from the less invariant part (geometry). The geometric characteristics such as orientation, shape, and proximity are not invariant. This separation between geometry and topology was done under the assumption that the topological structure is certain and does not change over time. New challenges to deal with the dynamic and uncertain topological structure require a reexamination of this fundamental assumption.

In the previous work we proposed a dynamic logic methodology for capturing, representing, and recording uncertain and dynamic topology and geometry jointly for spatial data fusion and mining. This work presents a further elaboration and formalization of this methodology as well as its application for modeling vector-to-vector and raster-to-vector conflation/registration problems.

8396-25, Session 3

Image and video-based remote target localization and tracking on smartphones

Q. Wang, A. Lobzhanidze, H. I. Jang, W. Zeng, Y. Shang, Univ. of Missouri-Columbia (United States)

Smartphones are becoming popular nowadays not only because of its communication functionality but also, more importantly, its powerful sensing and computing capability. In this work, we developed a novel and accurate image and video based remote target localization and tracking system using the Android smartphones, by leveraging its built-in sensors such as camera, digital compass, GPS, etc. Even though many other distance estimation or localization devices are available, our all-in-one, easy-to-use localization and tracking system on low cost and commodity smartphones is first of its kind. Furthermore, smartphones' exclusive user-friendly interface has been effectively taken advantage of by our system to facilitate low complexity and high accuracy.

Our system consists of three parts: first, Single Image Based Localization: assuming the physical size of the remote object is known, a few accurate corresponding point pairs between the image and the remote target will be identified by the user via a very simple interaction, and then the remote target's position could be found by applying POSTIT algorithm with some variation as well as combining the GPS and digital compass sensor readings. The distance estimation accuracy is up to 94%. Second, Two Images Based Localization: correspondences between two images of the same remote target are identified with SURF and epipolar geometry based algorithms are used to find the rotation and translation. Then together with other sensing information, multi-view triangulation algorithm is applied to find remote target's position. The distance estimation accuracy is around 83%. Third, Single Video Based Moving Object Tracking: a simple user input helps accurately and efficiently track target object and detect its boundary by leveraging Lucas-Kanade optical flow and our macro-block matching algorithms, and Kalman Filtering is applied to better estimate the target's trajectory as well as velocity.

The handy, low-cost, and all-in-one tracking and localization system on commodity smartphones is expected to have significant values for both military and commercial applications.

8396-26, Session 3

A spatial intensity phase evaluator (SIPHER) for perceptual object detection in images

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SIPHER is a means to make objects in a digital image vary in intensity with respect to other objects or backgrounds, in an unusual manner which promotes object or target cognitive perception. We describe this as objects being in or out of spatial intensity phase with one another. Simple surface reflectivity and a single, static illumination source provide no special means to distinguish objects from backgrounds, other than their reflectivity differences. However, if different surfaces are illuminated from different source positions or amplitudes, like from a moving spotlight, different pixels with the same reflectivity may have different amplitudes at different instances within the source's dynamic behavior. The problem is that we cannot always control source dynamics or collect images over sufficient time to exploit these dynamics. SIPHER simulates source dynamics in a single, static image. It creates apparent reflectivity changes in an image taken at one instance, as if the illumination source's intensity and position was changing, as a function of algorithm threshold settings. Cognitive perception is enhanced by creating a video sequence of the processed images. This produces an apparent motion effect in the object relative to its surroundings, or renders an apparent three-dimensional effect where the object appears to "jump out" from its surroundings. We first define this spatial intensity phase quantity mathematically, then compare it to conventional signal phase relationships, and finally apply it to some images to demonstrate its behavior. We also discuss anticipated enhancement and normalization techniques which may improve the technique in the future.

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8397-01, Session 1

Mathematical model and experimental analysis of multiple channel orbital angular momentum in spatial domain multiplexing

S. H. Murshid, H. Muralikrishnan, S. Kozaitis, Florida Institute of Technology (United States)

A novel multiplexing technique known as Spatial Domain multiplexing (SDM) has been developed in recent years and offers many advantages over its counterparts. With multiple channel transmission of same wavelength over a single multimode carrier fiber, it increases the data capacity by multiple folds. Input channels are launched at appropriate input angles to produce skew ray propagation. The output of the system when projected on a screen is observed as concentric rings. These SDM beams carry orbital angular momentum. Experiments show that two input sources with same launch conditions, but opposite topological charge take different helical paths inside the transmission fiber. Consequently the shadow of a straight wire does not remain straight anymore. Instead it is displaced by a certain distance. This endeavor presents a model of such a system by analyzing the shadow distortion, using principles of geometric optics. Experimentally obtained shadow displacement results are quantified and then compared to the model. We also show that when two channels with opposite topological charges are transmitted with same launch conditions, their orbital angular momenta are equal and opposite. As a result Orbital Angular Momentum based multiplexing can be used to add another degree of freedom to photons.

8397-02, Session 1

Orbital angular momentum in four channel spatial domain multiplexing system for multi-terabit per second communication architectures

S. H. Murshid, H. Muralikrishnan, S. Kozaitis, Florida Institute of Technology (United States)

Bandwidth increase has always been an important area of research in communications. A novel multiplexing technique known as Spatial Domain Multiplexing (SDM) has been developed at the Optronics Laboratory of Florida Institute of Technology to increase the bandwidth to T-bits/s range. In this technique, space inside the fiber is used effectively to transmit up to four channels of same wavelength at the same time. Experimental and theoretical analysis shows that these channels follow independent helical paths inside the fiber without interfering with each other. Multiple pigtail laser sources of exactly the same wavelength are used to launch light into a single carrier fiber in a fashion that resulting channels follow independent helical trajectories inside the carrier fiber. These helically propagating light beams form optical vortices inside the fiber and carry their own Orbital Angular Momentum (OAM). The outputs of these beams appear as concentric donut shaped rings when projected on a screen. This endeavor presents the experimental outputs and simulated results for a four channel spatially multiplexed system effectively increasing the system bandwidth by a factor of four.

8397-03, Session 1

Auto-compensating multi-user quantum key distribution network using a wavelength-addressed bus line architecture

E. Donkor, Univ. of Connecticut (United States)

A six-user quantum key distribution network based on the auto-compensating plug & play scheme is experimentally demonstrated. The network, which has a bus line topology, uses the BB84 protocol to transmit cryptographic keys encoded unto the phase states of highly attenuated laser light to distances of up to 30.9 km of standard telecommunication-grade fiber. Each user on the network is assigned a unique wavelength for communication with the network server. The quantum bit error rate and sifted key rate measured compares favorably with theory.

8397-04, Session 1

Co-site interference mitigation using optical signal processing

M. Lu, P. R. Prucnal, Princeton Univ. (United States)

Interference is a challenging problem in virtually all wireless systems, and co-site interference is a specific class of the interference problem where a receiver attempts to detect a weak signal in close proximity to a strong transmitter. While the co-site interference problem is found everywhere from wireless communication and environmental sensing networks, one of the most critical problem spaces is in military communications. The use of IED jammers introduces a serious co-site interference problem, because the powerful transmissions of the jammers overwhelm nearby receivers' ability to pick up weak signals, such as those generated by the troops' handheld radios.

Traditional interference cancellation solutions are electronics-based and their performance is consequently bandwidth-limited; electronic interference cancellation is also inhibited by the inability to cancel in-band interference. Our group has developed an optical technique for interference cancellation, and our signal processor, called the Opto-Cancellation System (OCS), is capable of cancelling both in-band interference as well as broadband signals over a wide range of frequencies. The OCS has demonstrated >60 dB cancellation of narrowband signals while also cancelling 100 MHz-wide signals by at least 40 dB cancellation over a full 20 MHz range.

While we have demonstrated proof-of-concept cancellation, it is important to better understand cancellation performance; specifically, we seek to explore a theoretical model of our optical interference cancellation, and determine the theoretical limitation of our approach as well as how well experimental results agree with the theory. Measures of noise, dynamic range, and frequency response are also used to help us better understand the limitations and advantages to our RF photonic link approach.

8397-05, Session 2

A variable mechanical optical attenuator

O. Shehab, Univ. of Maryland, Baltimore County (United States)

A new design of a variable mechanical optical attenuator is proposed in this paper. Mechanical attenuators are extensively important in designing optical communication systems. It is also highly used in testing and training purposes. The design consists a novel fiber optic

splitter-combiner setup. Each branch of the splitter meets a specific branch of the combiner. A fixed distanced multi-window rotary wheel slides between them. Upon rotation the light is either blocked or allowed to pass from a splitter branch to a combiner branch. By changing the number of open gates, the amount of yielded light can be controlled. There is only one moving part. So, the design is easy to manufacture, use or repair. The basic design and work flow is explained. The formula for calculating the attenuation and calibration guideline is also discussed. Then the design is compared with the other design standards based on the areas of application. The possible effects of linear and non-linear properties of light is also discussed. The primary concerns that should be taken if this design is to be fabricated in photonic integrated circuits is also mentioned briefly.

8397-06, Session 2

A passively modelocked laser with tunable pulse-repetition frequency in a semiconductor optical amplifier

E. Donkor, Univ. of Connecticut (United States)

We present experimental demonstration of a pulse-repetition frequency tunable passively modelocked laser using semiconductor optical amplifier as the gain medium. The laser is designed for the 1550nm telecommunication applications. The modelocking mechanism is explained in terms of normal mode splitting of the continuous-wave spontaneous emission signal from the semiconductor optical amplifier; arising from the coupling between a quantum cavity, represented by the semiconductor gain medium, and an optical cavity comprised of a high-birefringence fiber in line with a Faraday mirror. Experimental results are presented for pulse-repetition frequency tunability ranging between 93MHz and 1400MHz, as well as for the pulse-width which is measured to be 343ps. These results are shown to compare favorably with theoretical calculations.

8397-07, Session 2

Modeling InGaAsP/InP/Au distributed feedback lasers for optical communications

M. Shih, Univ. of Florida (United States)

The eye-safe 1.55 µm lightwave can have high transmittance through the atmosphere for free-space optical communication systems. Such systems with small semiconductor lasers can be constructed or modified easily, emergently, and economically so as to have flexible applications in defense, security, and disasters. Distributed feedback semiconductor lasers can generate more precise and stable wavelength to have better performance for communications. This model demonstrates how mode-coupling coefficients of semiconductor-metal distributed feedback lasers at 1.55 µm vary with metal grating geometry, semiconductor layer thickness, and materials. Floquet-Bloch and Ray-optics methods are used to calculate coupling coefficients and have close numerical results. With physical interpretation, this model can provide more insights into the design and modeling of such lasers.

8397-08, Session 2

Toward widely tunable narrow linewidth RF source through heterogenous silicon photonic integration

G. A. Ejzak, D. W. Grund, Jr., J. Murakowski, G. J. Schneider, D. W. Prather, Univ. of Delaware (United States)

Generating RF signals over the entire spectrum, from hundreds of MHz into the hundreds of GHz, has previously required the use of special oscillators designed only for specific bands of operation within that spectrum. By mixing two lasers together it is possible to generate RF signals over that entire band. Through the use of a narrow linewidth low frequency oscillator, optical modulator, and injection locking, much higher frequency outputs can be produced that still retain the narrow linewidth of the low frequency oscillator. Here we focus on the design and implementation of an integrated device including photonic sources and modulators to realize the system described above. Specifically we report on the creation and mixing of two tunable lasers on a single chip through heterogeneous integration of a silicon laser cavity coupled to an external gain chip realized in a III-V material system.

8397-09, Session 2

Experimental demonstration of an all optical flip flop memory

K. Kaltenecker, E. Donkor, Univ. of Connecticut (United States)

We present an experimental demonstration of an all optical flip flop consisting of a coupled system of a semiconductor optical amplifier and a super continuum generator operating in the 1500 nm range. The circuit is designed as a fiber ring consisting of the semiconductor amplifier, a polarization beam splitter, a digital polarization controller, a polarization maintaining fiber and a super continuum generator in series. The P or the S output of the beam splitter is sent to an optical spectrum analyzer to measure the output while the other output completes the ring. The linear polarization is adjusted with a digital polarization controller. The stable state consists of two modes, where the mode amplitude represents the state. Mode 1 corresponds to 1530 nanometers and mode 2 corresponds to 1550 nanometers. A contrast ratio between an “on” and “off” state is measured for each mode. The stable states of the flip flop are [mode1-ON, mode2- ON], [mode 1-ON, mode 2-OFF], [mode1-OFF, mode 2-ON] and [mode 1-OFF, mode 2-OFF] and are controlled by the polarization. We shall present the state diagram for these four states of the flip flop, the effect of power on the system, the effect of the SOA drive current, and the effect of polarization fluctuations.

8397-10, Session 3

Military laser transmitter incorporating an optical sub-assembly module

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Recently, the wireless optical communication based on free space optics was extensively used for the multiple integrated laser engagement systems (MILES), which is a tactical engagement simulator used in realistic battlefield scenarios. A laser transmitter for the training system involves an infrared beam. It transmits an encoded message simulating weapon firing characteristics, even with hit or near-miss events taken into consideration. The initial alignment of the transmitter with the weapon’s line of sight can be substantially facillitated by taking advantage of an auxiliary visible laser beam.

In this work, we have proposed and built a compact military laser transmitter providing precision aligned visible/infrared beams, exploiting an optical sub-assembly module. The visible and infrared diode lasers were combined via a beam combiner and coupled to a collimating lens, in order to obtain highly collinear collimated beams. The IR beam is responsible for delivering simulated bullets, while the visible beam is used to align the IR beam during the installation. For the achieved performance, the alignment angle between the visible and infrared beam was less than 0.01o. The IR beam from the fiber consisted of two different beam divergence angles of ~1.5 and 10 mrad, which was found to be useful for covering long range and short range, respectively. The manufactured transmitter was observed to provide an effective shooting range of 700 m with a beam width of 50 cm. The length of transmitter was especially as small as ~4 cm, similar to that of conventional IR-only transmitter.

8397-11, Session 3

Highly angle tolerant MILES receiver incorporating an infrared etalon filter

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Free space optics based optical communication has received enormous attention in view of its various applications such as multiple integrated laser engagement systems (MILES), which is a tactical engagement simulator that facilitates military trainings in a realistic battlefield scenario. A MILES receiver is required to detect the infrared light ~900 nm delivered by the laser transmitter. An efficient IR bandpass filter needs to be incorporated into the receiver in order to suppress the surrounding noises such as the sunlight, while the receiver is required to be highly angle tolerant with respect to the incident light beam.

In this work, we have proposed and built a highly angle tolerant MILES receiver incorporating multiple detector units, each of which is prepared by integrating a silicon photodiode with a compound IR bandpass filter. This proposed filter is composed of a Fabry-Perot Ag-TiO2-Ag etalon, centered at ~900 nm, which is combined with a visible light blocking filter with a cutoff wavelenght of ~850 nm. A group of detector units were appropriately arranged in order to extend the angular tolerance up to 160 degrees. Moreover, the proposed MILES receiver was tested to provide a robust operation even in the presence of the background noise such as the sunlight, as anticipated.

8397-12, Session 3

2D real-time arithmetic operations using optical coherence properties: image processing applications

B. Benkelfat, S. Elwardi, TELECOM & Management SudParis (France); M. Zghal, SUP'COM (Tunisia); A. Alfalou, Institut Superieur de l'Electronique et du Numerique (France)

We report for the first time the use of the well-known coherence modulation of light in two-dimensional arithmetic operations. This method permits parallel real-time all optical subtractions and additions. The single-channel optical architecture, which allows carrying out single and multiple arithmetic operations, is described and more results are presented to show the effectiveness of our technique.

The coherence modulation of light (also called path-difference modulation) consists in encoding a signal on a light beam as an optical path-difference larger than its coherence length. The different signals to be processed are encoded by two-dimensional spatial coherence modulators (S-CM's) set in cascade. Each S-CM, which consists of a liquid crystal spatial light modulator and a birefringent plate placed between two polarizers, introduces an optical path difference (OPD) greater than the coherence length of the light source. This OPD is chosen to minimize the channel cross talk. An achromatic optical system performs the image of input plane on a CCD camera through a decoding module. The latter is formed by an electro-optical two-wave interferometer, such as liquid crystal cell, tuned on a specific OPD and set between two polarizers.

The preliminary results have been obtained with two S-CM's single-channel optical architecture. They are in perfect accordance with the theoretical predictions. We have shown that the successful implementation of this SCM-based system depends on the "optical isolation" between the signals to be processed. We have evaluated the performance of the processor in terms of noise level as a function of the continuous OPD ratio.

8397-13, Poster Session

Photonic beamsteering of multiple RF beams via a wavelength routing true-time delay matrix

M. Plascak, T. McKean, S. Granieri, A. Siahmakoun, Rose-Hulman Institute of Technology (United States)

We present a photonic beamformer using wavelength-switching of delay lines for beamsteering of multiple simultaneous-independent RF beams in receive mode. The proposed architecture implements true-time delay (TTD) through a set of fiber Bragg grating (FBG) arrays that controls all elements of a phased-array antenna. Optical carriers from a tunable or multichannel optical source are split, amplified, and sent through a set of NxM electro-optic modulators. Carriers are therefore intensity modulated with the RF signal received by the antenna elements. Optical carriers are directed to a set of NxM FBG-based delay lines where each carrier picks up a proper true-time delay to compensate the RF phase shift produced by the arriving angle at the antenna. Optical carriers are then combined, demultiplexed, and demodulated using photodetectors. The obtained electrical signals are amplified, filtered and sent to the RF detection system. In this approach the direction of the incident RF beam is determined analyzing the optical power and wavelength of the optical carrier through FBG delay lines that select the optical path of each carrier in the C-band for each T/R element of the antenna. This method provides high-resolution beamsteering that is immune to EMI. Furthermore, this technique will not require any commercially available optical switching technologies and thus will remove the need for any electronic control and manipulation of the fiber-optic TTD matrix. In this implementation the number of required optical carrier depends on the resolution of the beam steering angles (in both azimuth and elevation directions) times the number of RF beams and is independent of number of T/R elements.

8397-14, Poster Session

Transmitter for free-space optics with an integrated driver

J. Mikolajczyk, Z. Bielecki, J. Wojtas, D. Szabra, M. Nowakowski, M. Gutowska, B. Rutecka, R. Medrzycki, Military Univ. of Technology (Poland)

The paper presents a free space optical transmitter operating in the wavelength range of 8-12 um. The transmitter consists of a laser head and a driving system to control a quantum cascade laser operation parameters. In the head, optics adjustment unit, quantum cascade laser, Peltier modules, and a temperature sensor are mounted. The developed driver provides to control the laser radiation energy, repetition rate and duration of radiation pulses and to stabilize the operating temperature. In the described transmitter, generation of pulses with high duty cycle is also provided, making it possible to use the data link with either RZ or NRZ coding. In the frame of the study, the impact of laser operation conditions on the data range and the bandwidth of the transmission link was determined. The optimization process was carried out taking into account power of laser pulses and cooling conditions. The results were compared with data obtained using a specialized pseudorandom data generator and a power supply with so-called Bias-T unit.

8397-15, Poster Session

An integrated driver for quantum cascade lasers

J. Mikolajczyk, Military Univ. of Technology (Poland); R. Niedbala, M. Wesolowski, Warsaw Univ. of Technology (Poland); Z. Bielecki, J. Wojtas, D. Szabra, Military Univ. of Technology (Poland)

The paper presents a design and investigations of a new driver for quantum cascade (QC) lasers. The device consists of a digital controller of both laser current and laser temperature. The driver is designed to operating with pulse and CW mode QC lasers. The current pulses can be precisely tuned in a wide range of both amplitude and duty cycle variations. For both laser mode operations, there is the possibility to set a laser current in the range of 0.1 - 3 A. The driver provides generation of pulses with a minimum duration of 30 ns at frequencies above 15 MHz. The cooling system is based on Peltier modules and multi-loop microprocessor controller. The stabilization of the temperature in the range of 50 ÷ -40 °C with min. accuracy of 0.5 K is obtained. Preliminary investigations of the influence of laser operating condition changes on driver stabilizing properties were performed. The main advantage of the driver is its compact design, easy software control, the possibility of a full synchronization with external pulses. These features make the driver very useful in a construction of free space optical transmission systems (FSO) and laser absorption spectroscopy setups. In the final part of the article, successful research with FSO transmitter module and spectroscopy setup using the developed driver are presented.

8397-16, Poster Session

Photonic analog-to-digital converter with asynchronous oversampling technique

S. Carver, S. Granieri, A. Siahmakoun, Rose-Hulman Institute of Technology (United States)

Analog-to-digital conversion when performed in the optical domain can improve processing speeds as well as diminish adverse effects present in electronic analog-to-digital converters such as electromagnetic interference. Potential applications for this technology include RF instrumentation, processing of microwave signals, and digital beamforming. The proposed architecture is a hybrid opto-electronic asynchronous delta-sigma modulator, chosen for its independence of an external clock and ease of demodulation through a single low-pass filter stage. The fiber-optic prototype consists of an input laser operating at 1 which is modulated with an input RF signal. A fiber-optic loop that includes a semiconductor optical amplifier and band-pass filter that act as a leaky integrator and a wavelength converter. The integrator inverts the input signal through cross-gain modulation as well as changes the wavelength of the optical carrier to 2. The signal from the integrator is coupled into a photodetector for optical-to-electrical conversion. The signal in the electric domain is sent through a high-speed comparator circuit that acts as a bi-stable quantizer. The binary NRZ signal from the comparator is used to modulate a second laser operating at 1. This signal is split; where 90% of optical power is sent back into the integrator as a positive-corrective feedback, and 10% to an oscilloscope to observe the system binary output. This prototype is characterized at sampling rate of 15.4 MS/s processing analog input signals in the range of 0-3 MHz with a signal-to-noise ratio of 36 dB, spur-free dynamic range 26 dB, and an effective number of bits of 5.7

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8398-01, Session 1

Detection and identification of oil and oil-derived substances at the surface and subsurface levels via hyperspectral imaging

M. S. Alam, R. P. Gollapalli, S. Paheding, Univ. of South Alabama (United States)

The BP Deepwater Horizon drilling rig explosion in the Gulf of Mexico released 206 million gallons of crude oil contaminating the Gulf waters along with 665 mile stretch coastline of Texas, Louisiana, Mississippi, Alabama and Florida. Accurate detection and estimation of the oil at the surface, subsurface and ocean floor is essential for the cleaning and mitigation efforts. It is critical to develop a quick-response technique to detect, identify and track the oil spills to facilitate efficient clean-up and minimize the impact of oil spills to the environment, economy, human life and other living organisms.

Existing techniques are limited in scope as they cover only small regions of interest (RoI). On the other hand, optical remote sensing based techniques, such as hyperspectral imaging can provide information over vast regions of interest. Hyperspectral imaging can provide information in minute details on the spread of the surface and subsurface oil and oil derived substances which can assist in the containment and mitigation efforts before the oil spill can become a full-blown catastrophe.

Current techniques can detect and identify surface oil but fail to address the critical issue of detecting subsurface oil and estimate the depth where the oil is present. In this paper, we developed an algorithm for detecting both surface and subsurface oil using hyperspectral imagery. In this technique, a support vector machine (SVM) based classifier is trained using potential ROIs to classify the oil/oil-derived substances at the surface and subsurface levels using AVIRIS data available from the Jet Propulsion Laboratory. The proposed technique provides an efficient way for estimating the amount of oil as well as the depth of the subsurface oil location, which may provide crucial information in the containment, mitigation and clean-up efforts. Test results using AVIRIS data is presented to verify the effectiveness of the proposed technique.

8398-02, Session 1

A self-organized learning strategy for object recognition by an embedded line of attraction

M. Seow, BRS Labs. (United States); A. T. Alex, V. K. Asari, Univ. of Dayton (United States)

The human brain processes enormous volumes of high-dimensional data for everyday perception. To humans, a picture is worth a thousand words, but to a machine, it is just a seemingly random array of numbers. Although machines are very fast and efficient, they are vastly inferior to humans for everyday information processing. Algorithms that mimic the way the human brain computes and learns may be the solution. In this paper we present a theoretical model based on the observation that images of similar visual perceptions reside in a complex manifold in a low-dimensional image space. The perceived features are often highly structured and hidden in a complex set of relationships or high-dimensional abstractions. To model the pattern manifold, we present a novel learning algorithm using a recurrent neural network. The brain memorizes information using a dynamical system made of interconnected neurons. Retrieval of information is accomplished in an associative sense. It starts from an arbitrary state that might be an encoded representation of a visual image and converges to another state that is stable. The stable state is what the brain remembers. In designing a recurrent neural network, it is usually of prime importance to guarantee the convergence in the dynamics of the network. We propose to modify this picture: if the brain remembers by converging to the state representing familiar patterns, it should also diverge from such states when presented with an unknown encoded representation of a visual image belonging to a different category. That is, the identification of an instability mode is an indication that a presented pattern is far away from any stored pattern and therefore cannot be associated with current memories. These properties can be used to circumvent the plasticity-stability dilemma by using the fluctuating mode as an indicator to create new states. We capture this behavior using a novel neural architecture and learning algorithm, in which the system performs self-organization utilizing a stability mode and an instability mode for the dynamical system. Based on this observation we developed a self-organizing line attractor, which is capable of generating new lines in the feature space to learn unrecognized patterns. Experiments performed on UMIST pose database and CMU face expression variant database for face recognition have shown that the proposed nonlinear line attractor is able to successfully identify the individuals and it provided better recognition rate when compared to the state of the art face recognition techniques. Experiments on FRGC version 2 database has also provided excellent recognition rate in images captured in complex lighting environments. Experiments performed on the Japanese female face database using the self organizing line attractor have also shown successful classification of different facial expressions. These results show that the proposed model is able to create nonlinear manifolds in a multidimensional feature space to distinguish complex patterns.

8398-03, Session 1

A compressive sensor concept for automatic target detection

A. Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

No abstract available

8398-04, Session 1

Overview of pattern recognition research at NIST IAD

A. Talukder, National Institute of Standards and Technology (United States)

No abstract available

8398-05, Session 2

Optimization of support vector machine (SVM) for object

classification

M. Scholten, N. Dhingra, T. T. Lu, T. Chao, Jet Propulsion Lab. (United States)

No abstract available

8398-07, Session 2

Active imaging technique for sensor data reconstruction and identification

A. U. Sokolnikov, Visual Solutions and Applications (United States)

Active imaging (AI) is necessary for measuring parameters of the objects that do not give out or reflect a specific type of radiation. AI systems

offer a number of advantages over passive imaging systems that operate at visible through near-infrared wavelengths and usually rely on solar illumination. The reliability and precision of the target identification depends on how the signal received from a sensor is processed. Often, obstacles or the imperfection of the sensors and processing electronics cause loss of some of the information. The technique of processes with missing data is suggested as part of time series prediction and analysis. Thus, the image may be reconstructed even if the necessary data is partially absent in the input signal. The suggested method reduces the false alarm rate of the target identification. Results are provided.

8398-08, Session 2

A computationally efficient appearance-based algorithm for geospatial object detection

D. Arslan, A. A. Alatan, Middle East Technical Univ. (Turkey)

A computationally efficient appearance-based algorithm for geospatial object detection is presented and evaluated for aircraft detection from satellite imagery. An aircraft operator exploiting the edge information via gray level differences between the aircraft and its background is constructed with Haar-like polygon regions using the shape information of the aircraft as an invariant. The aircrafts matching the aircraft operator are supposed to yield higher responses around the centroid of the vehicles. Fast evaluation of the aircraft operator is achieved by means of integral image. Following the calculation of the integral image, the response to the aircraft operator is then computed in constant time for each pixel in the image with arithmetic operations, namely; summation, subtraction and multiplication of the polygon regions with a scalar constant. Rotated integral images are utilized for detecting aircrafts in various orientations. After computing the response image to the aircraft operator, the points yielding higher responses compared to a threshold, which have a peaky behavior around a defined neighborhood, are obtained and stored as possible aircraft centroids. Multiple hits occurring around the centroid of the aircrafts are merged by mean shift clustering algorithm. Experiments are conducted on satellite images taken from various airport regions and promising results are obtained. The detection performances for different threshold levels are presented by means of precision and recall measures. Among tested various satellite images of 0.5 m resolution including 300 target aircrafts of various sizes, the proposed algorithm has resulted with typical values of 77% and 85% for precision and recall, respectively.

8398-09, Session 3

Towards an all-numerical implementation of correlation

A. Alfalou, Institut Superieur de l'Electronique et du Numerique (France); C. Brosseau, Univ. de Bretagne Occidentale (France); B. Benkelfat, TELECOM & Management SudParis (France); S. Qasmi, Institut Superieur de l'Electronique et du Numerique (France)

Interestingly, the past 20 years have provided us many examples of optical correlation methods for pattern recognition, e.g. VanderLugt correlator. In recent years, hybrid techniques, i.e. numerical implementation of correlation, have been also considered an alternative to all-optical methods because they show a good compromise between performance and simplicity. Moreover, these correlation methods can be implemented using an all-numerical and reprogrammable target such as the graphics processor unit (GPU), or the field-programmable gate array (FPGA). However, this numerical procedure requires realizing two Fourier Transforms (FT), a spectral multiplication, and a correlation plane analysis. The purpose of this study is to compare the performances of a numerical correlator based on the Fast Fourier Transform (FFT) with that relying on a simulation of the Fraunhofer diffraction. Different tests using the Pointing Head Pose Image Database (PHPID) and considering faces with vertical and horizontal rotations were performed with the code MATLAB. Tests were conducted with a five reference optimized composite filter. The Receiving Operating Characteristics (ROC) curves show that the optical FT simulating the Fraunhofer diffraction leads to better performances than the FFT. The implications of our results for correlation are discussed.

8398-10, Session 3

An adapted optical correlation method sensitive to color changes in the target image

M. Elbouz, A. Alfalou, Institut Superieur de l'Electronique et du Numerique (France); M. S. Alam, Univ. of South Alabama (United States); S. Qasmi, Institut Superieur de l'Electronique et du Numerique (France)

Optical correlation is based on the comparison of contours between the unknown target image and the known reference image. However, it does not include the color-image information in the decision making process. In order to make the correlation method sensitive to color change in the target object, the target image is decomposed into its three color components using the normalized RGB (Red Green Blue) method or normalized HSV (Hue, Saturation, Value) Method. Then the correlation operation is carried out for each color component and the results are merged in order to arrive at one decision. The aforementioned steps may alleviate some of the problems associated with illumination changes in the target image but do utilize color information of the target image. To overcome these problems, we propose herein to convert the color information in contour information into a signature corresponding to the color information in the target image. Preliminary results obtained using the proposed technique are encouraging and shows excellent. Detailed analysis and test results are presented to validate the effectiveness of the proposed technique.

8398-11, Session 3

Target tracking using nonlinear reference phase-encoded joint transform correlation

M. N. Islam, Farmingdale State College (United States); V. K. Asari, Univ. of Dayton (United States); M. A. Karim, Old Dominion Univ. (United States); M. S. Alam, Univ. of South Alabama (United States)

Optical joint transform correlation (JTC) has been proven to be an efficient pattern recognition tool, especially, for real-time applications. However, the classical JTC suffers from a lot of limitations such as broad correlation peaks, large side lobes, duplicate correlation peaks and low discrimination between target and non-target objects. This paper proposes a nonlinear JTC based target detection and tracking technique, where the reference image is phase-shifted and phase-encoded and then fed to two parallel processing channels. Each channel introduces the unknown input scene and performs Fourier transformations to obtain the joint power spectra signals, which are then combined and phase-encoded. Then a nonlinear operation is performed on the modified power spectrum followed by the application of fringe-adjusted filtering operation. A subsequent inverse Fourier transform operation yields the correlation output containing a highly distinct peak corresponding to each target present in the input scene. The reference image phase-encoding process removes any overlapping issue among the input scene objects, which is a drawback of classical JTC technique. An updated decision criterion is developed for the correlation plane so that it can accurately identify the location of the target. The proposed pattern recognition technique offers an excellent alternative for target tracking in an unknown video sequence.

8398-12, Session 3

Optical multichannel correlators for high-speed targets detection, recognition, and localisation

V. L. Perju, National Council for Accreditation and Attestation (Moldova); D. Casasent, Carnegie Mellon Univ. (United States)

There are presented the results of the elaboration and investigation of the optical correlators with distributed functions of the targets detection, recognition and localization realized in different channels. There are presented the stuctures of the correlators, the results of the time and reliability investigations. This approach permit to obtain high speed at the stage of the targets detection and recognition. The high reliability of calculation is obtained due to using of the codified correlation maxima.

8398-13, Session 4

Improving OT-MACH filter performance for target recognition applications with the use of a Rayleigh distribution filter

A. T. Alkandri, N. Bangalore, A. Gardezi, P. Birch, R. C. Young, C. Chatwin, Univ. of Sussex (United Kingdom)

An improvement to the wavelet-modified Optimal Trade-off Maximum Average Correlation Height (OT-MACH) filter with the use of the Rayleigh distribution filter is discussed. The Rayleigh distribution filter is applied to the OT-MACH filter to provide a sharper low frequency cut-off and than the Laplacian of Gaussian based wavelet filter that has been previously reported to enhance OT-MACH filter performance. Filters are trained using 3D CAD models and tested on real target objects in high clutter environments acquired from the AH-64 helicopter mounted Forward Looking Infra Red (FLIR) sensor. Comparative evaluation of the performance of the original, wavelet and Rayleigh modified OT-MACH filter is reported for the recognition of the target objects present within the thermal infra-red image data set.

8398-14, Session 4

Composite wavelet filters for enhanced automated target recognition

J. Chiang, Y. Zhang, T. T. Lu, T. Chao, Jet Propulsion Lab. (United States)

No abstract available

8398-15, Session 4

Adaptive filtering with organic photorefractive materials via four-wave

mixing

J. Khoury, Air Force Research Lab. (United States); J. J. Donoghue, Solid State Scientific Corp. (United States); B. Haji-saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States); N. N. Peyghambarian, College of Optical Sciences, The Univ. of Arizona (United States); M. Yamamoto, Nitto Denko Technical Corp. (United States)

In prior work, we exploited the nonlinearity inherent in four-wave mixing in organic photorefractive materials for adaptive filtering. In this paper, we extend our work further and demonstrate new applications which involve: dislocation, scratches and defect enhancement. With the availability of the organic photorefractive materials with large space-bandwidth product, it should open the possibility of using the adaptive filtering techniques in quality control systems.

8398-16, Session 4

Variants of minimum correlation energy filters: comparative study

N. N. Evtikhiev, D. V. Shaulskiy, E. Y. Zlokazov, R. S. Starikov, National Research Nuclear Univ. MEPhI (Russian Federation)

Application of distortion invariant filters (DIF) provides the possibility of invariant image recognition with increased speed of correlation matching. DIF with the minimization of correlation energy enable to control the properties of output correlation signal due to the parameterization during its synthesis. There are several types of such a filters presented nowadays. The relevance degree of each type of filter application is determined by the specific conditions of the recognition task. Thus it requires a comparative analysis of the filters performance. The simulations were provided for the DIF of the following types: (Minimum Average Correlation Energy Filter), GMACE (Gaussian-minimum average correlation energy filters), MINACE (Minimum noise and correlation energy filter) and WMACE (the version of GMACE where the smoothing function is the wavelet). The synthesis of filters was carried out under identical conditions of gray-scale image recognition problem (out of plane rotated objects). The comparison results of discrimination characteristics and the requirements of DIFs synthesis are described and discussed.

8398-23, Poster Session

Design and simulation of a multiport neural network heteroassociative memory for optical pattern recognitions

V. G. Krasilenko, Vinnitsa Social Economy Institute (Ukraine); A. A. Lazarev, Vinnytsia National Technical Univ. (Ukraine); S. Grabovlyak, Vinnitsa Social Economy Institute (Ukraine)

The modified matrix equivalently models (MMEMs) of multiport neural network heteroassociative memory (MP_NN_HAM) with double adaptive - equivalently weighing (DAEW) for recognition of 1D and 2D-patterns (images) are offered. It is shown, that computing process in MP_NN_HAM under using the proposed MMEMs, is reduced to two-step and multi-step algorithms and step-by-step matrix-matrix (tensor-tensor) procedures. The base operations and structural components for construction of MP_NN_HAM are matrix-matrix multipliers and matrixes of nonlinear converters, including threshold transformations. Advantages of such MMEMs for MP_NN_HAM were shown and confirmed by computer simulation results. The aim of paper is research of improved models and MP_NN_HAM for input 1D and 2D signals with unipolar coding and their capacity determination. The given results of computer simulations confirmed the perspective of such models. Results were also received for case of a MP_NN_HAM on base of MMEMs capacity exceeded a neurons amount. This memory is intended to recognize parallel and refresh P input distorted images (N-element vector). Such MP_NN_HAM is a kind of combination consisting of P independently functioning NN_HAM with common memory. Variants of optical realization of MP_NN_HAM architectures are considered in paper. A whole system is consists of two matrix-matrix (for 1D patterns) or two tensor-tensor (for 2D patterns) equivalentors (E) (or nonequivalentors (NE)) (MME and MMNE or TTE and TTNE).The proposed E (or NE) architecture with temporary integration has more large dimension of HAM and more simple design.

8398-24, Poster Session

The investigation of the Fourier spectrum-based image complexity metrics for recognition applications

V. L. Perju, National Council for Accreditation and Attestation (Moldova); D. Casasent, Carnegie Mellon Univ. (United States); L. Ababei, Free International Univ. of Moldova (Moldova)

Image complexity matrix is one of the very important parameters necessary to control the architectures and computing processes in automatic pattern and target recognizers, image processing systems, computer visions applications etc.

In article it is described the image complexity matrix, which is based on the Fourier spectrum maximal frequencies determi¬nation and its form's taking into consideration. This measure of complexity may be obtained rather easily and fast by optical and optical electronic means, which is very important in realization of the real time mode functioning systems.

It was made the experimental estimation of the image complexity of the objects of different classes which are very close to the subjective estimation of the image complexity. This fact confirms the possibility of the practical utilization of the proposed image complexity matrix.

It was studied the influence of the image complexity on the required image resolution which show that at the decreasing of the image resolution the image complexity also is decreased. Required resolution of the image and total number of the pixels which have to be processed depends very much from the image complexity.

It was examined the influence of the resolution (and, respectively, the image complexity) on the accuracy of the objects recognition, based on the correlation functions calculation which show that at increasing the image resolution the relations aoutocorrelation to maximal crosscorrelation function increase, and respectively, it will increase the probability of correct objects recognition.

There are presented the structures of the optical processors for image complexity matrix determination.

8398-25, Poster Session

Hybrid optical-digital encryption system based on wavefront coding paradigm

M. V. Konnik, The Univ. of Newcastle (Australia)

The wavefront coding is a widely used in the optical systems to compensate aberrations and increase the depth of field. This paper presents experimental results on application of the wavefront coding paradigm for data encryption. We use a synthesised diffractive optical element (DOE) to deliberately introduce a phase distortion during the images registration process to encode the acquired image. In this case, an optical convolution of the input image with the point spread function (PSF) of the DOE is registered. The encryption is performed optically, and is therefore is fast and secure. Since the introduced distortion is the same across the image, the reconstruction is performed digitally using deconvolution methods. However, due to noise and finite accuracy of a photosensor, the reconstructed image is degraded but still readable.

The experimental results, which are presented in this paper, indicate that the proposed hybrid optical-digital system can be implemented as a portable device using inexpensive off-the-shelf components. We present the results of optical encryption and digital restoration with quantitative estimations of the images quality. Details of hardware optical implementation of the hybrid optical-digital encryption system are discussed.

8398-26, Poster Session

Development of a novel image processing method, the LPED method

C. J. Hu, Southern Illinois Univ. Carbondale (United States)

Local polar-edge detection (LPED) method is a novel method the author used in several computerized image processing systems in the last 3 years. It uses a novel edge-detection method to detect the boundary points of a group of size-selected objects embedded in a large IR or optical image frame. Then it uses a 2-D clustering method to cluster all boundary points into N sub-groups with each sub-group representing one particular object. This is to be followed by finding the center of mass point, or CMP, of each sub-group. From each sub-group the program then automatically finds 36 radial distances between the CMP and the boundary. A 36-dimension analog vector can then be constructed from these 36 radial distances. This 36D analog vector is the ID vector to identify the object that has this particular boundary. This ID vector is independent of the location and independent of the image size of the object. But it is a unique property for tracking and targeting of the particularly shaped object, specially when the object is moving and the focusing is not very sharp. The tracking and targeting can be done in real-time because of the super-short time used to implement the novel algorithm.

The advantages of this LPED method over most conventional edge-detection methods and some live experiments using the system will be explained and demonstrated in detail.

8398-27, Poster Session

Using wavefront coding technique as an optical encryption system: reliability analysis and vulnerabilities assessment

M. V. Konnik, The Univ. of Newcastle (Australia)

The wavefront coding paradigm can be used not only for the compensation of aberrations and the improvement of depth-of-field but also for the optical encryption. An optical convolution of the input scene with the PSF occurs when a diffractive optical element (DOE) with a known point spread function (PSF) is placed in the optical path. Therefore, the result of the optical convolution (encrypted image) is registered by a photosensor instead of the true image of the input scene. Decoding of the registered image can be performed using standard digital deconvolution methods.

In such a class of optical-digital systems, the PSF of the DOE is used as an encryption key. Therefore, the reliability and cryptographic resistance of such an encryption method depends on the size and complexity of the PSF used for optical encoding. This paper gives a preliminary analysis on reliability and possible vulnerabilities of such an encryption method based on wavefront encoding. Experimental results for a brute-force attack on the optically encrypted images are presented. Reliability of the resulting estimation of optical encryption based on wavefront coding paradigm is evaluated. An analysis of possible vulnerabilities is provided.

8398-17, Session 5

Compact liquid crystal waveguide Fourier transform spectrometer

for real-time gas sensing in NIR spectral band

T. Chao, T. T. Lu, Jet Propulsion Lab. (United States); S. Davis, G. Farca, S. D. Rommel, Vescent Photonics Inc. (United States)

No abstract available

8398-18, Session 5

A secure approach for encrypting and compressing biometric information employing orthogonal code and steganography

M. F. Islam, George Washington Univ. (United States); M. N. Islam, Farmingdale State College (United States)

Steganography has become a popular technique utilized by information security professionals in order to embed secret information into a cover image which then becomes undetectable by human eyes. In this paper, a novel approach is proposed for encryption and compression of biometric information utilizing orthogonal coding and steganography techniques. Multiple biometric signatures, such as fingerprints and iris scans, are encrypted individually using orthogonal codes and then multiplexed together to form a single image. Because of orthogonal nature of the coding scheme, individual biometric information can easily be retrieved at the receiving end without any interruption or distortion. The resulting encrypted image is then embedded in a cover image using the proposed steganography technique. Instead of using only the least significant bit (LSB), which is being traditionally used, the proposed technique employs three LSBs to embed the encrypted biometric data. A secret key is also developed to choose one from among the three bits which would be replaced by the corresponding bit of the biometric image. The proposed bit replacement technique will enable secure embedding of images against statistical analysis based detection. One will then require two sets of keys in order to obtain original binary biometric signatures - one key for steganography and another for orthogonal encryption. The proposed technique employs a simple architecture, yet provides with a very efficient mechanism to compress biometric data and to secure confidential information. The proposed technique can be useful and efficient in transmitting highly secure information and embedding multiple biometric signatures in secure documents such as employee identification cards, immigration documents, driver's licenses, passports and passport cards.

8398-19, Session 5

Spatial domain sharpening of color image employing bidimensional empirical mode decomposition

S. M. A. Bhuiyan, J. F. Khan, Tuskegee Univ. (United States); M. S. Alam, Univ. of South Alabama (United States)

Image sharpening is an image processing technique that highlights transitions in intensity. This paper formulates a bidimensiinal empirical mode decomposition (BEMD) based spatial domain image sharpening and extends it for color images, where sharpening highlights the color separations besides depicting intensity transitions. In this approach, the color image is first decomposed into several hierarchical components using BEMD, which is a multi-scale/multi-resolution technique. The hierarchical image components are known as bidimensional empirical mode functions (BEMFs), where the first BEMF contains the highest local spatial variation, and the final BEMF contains the trend of the image, which is also known as residue. However, instead of using classical BEMD, a modified BEMD is utilized, which is known as fast and adaptive BEMD, and which uses order-statics filters for envelope estimation in the process, instead of surface interpolation. The BEMD developed for color images, known as color BEMD (CBEMD), decomposes a color image into several color BEMFs (CBEMFs), where each CBEMF has all three color components. Since the first BEMF contains the finest spatial variations, it provides an approximate edge map of the image highlighting intensity transitions. In one approach, traditional sharpening method such as Laplacian or high-boost filtering is applied to the first BEMF instead of applying to the original image. In another approach, suitable weighting of the first BEMF is done instead. In case of color images, the same process is performed on all three color components of the first BEMF. Finally, the image is reconstructed from the addition of all the BEMFs for gray scale image or all the CBEMFs for color image to obtain the desired sharpening. It has been observed that the proposed BEMD based method provides improved image/color image sharpening compared to the traditional methods.

8398-20, Session 5

Automated detection of semagram-laden images using adpative neural networks

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Digital media that are easy to steal, such as graphics, photos and audio files, are being tagged with both visible and invisible copyright stamps (known as digital watermarking). However, these same techniques can also be used to hide communications between actors in criminal or covert activities. An inherent difficulty in detecting digital steganography is overcoming the variety of methods for hiding a message and the multitude of choices of available media. Another problem in steganography defense is the issue of detection speed since the encoded data is frequently time-sensitive. When a message is visually transmitted in a non-textual format (i.e., in an image) it is referred to as a semagram. Semagrams are relatively easy to create, but very difficult to detect. While steganography can often be identified by detecting digital modifications to an image's structure, an image-based semagram is more difficult because the message is the image itself. The work that will be presented describes the creation of a novel, computer-based application, which uses hybrid hierarchical neural network architectures to detect the likely presence of a semagram message in an image. The prototype system was used to detect semagrams containing Morse Code messages. Based on the results of these experiments our approach provides a significant advance in the detection of complex semagram patterns. Specific results of the experiments and the potential practical applications of the neural network-based technology will be discussed. This presentation is a follow up to our 2010 presentation and provides the final results of our research experiments.

8398-21, Session 5

Characterization of optical correlation via dynamic range compression using organic photorefractive materials

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In prior work, we demonstrate optical correlation via dynamic range compression in two-beam coupling using thin-film organic materials. In this paper, we continue the effort; characterize the performance of this correlator for variety of input. We successfully demonstrated correlation results almost free of cross- correlation and noise for extremely complicated noisy image were the signal image consist of several targets and reference image superposed of many templates.

8398-22, Session 5

A new time-adaptive, discrete, bionic-wavelet transform for enhancing speech from adverse noise environment

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Several automatic speech processing systems have also found their way in everyday life through their use in mobile communication, speech and speaker recognition and aid for the hearing impaired. In all these speech communication systems the quality and intelligibility of speech is of utmost importance for ease and accuracy of information exchange. To obtain a more intelligible speech signal and one that is more pleasant to listen, noise reduction is needed. A new time adaptive discrete bionic wavelet thresholding (TADBWT) is proposed using Daubechies mother wavelet to achieve better enhancement of speech from additive non stationary noises effectively which occur in real life like street noise, factory noise. Due to the integration of human auditory system model into the wavelet transform, Bionic wavelet transform has great potential in speech enhancement and may lead to a new path in speech processing. In this method firstly, discrete BWT of noisy speech is taken to derive TADBWT coefficients. Then the adaptive nature of the BWT is captured by introducing a time varying linear factor that updates the coefficients at each scale over time. It has is shown better performance than the existing algorithms at lower input SNR due to modified soft level dependent thresholding on time adaptive coefficients. The objective and subjective test results proved the competency of TADBWT. The effectiveness of this method is also evaluated in the speaker recognition task under noisy environment. The recognition results show that TADWT method give relatively higher performance than other methods specifically at lower input SNR.

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8399-01, Session 1

Toward automatic subpixel registration of unmanned airborne vehicle images

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Many applications require to register images within subpixel accuracy like computer vision especially super-resolution (SR) where the estimated subpixel shifts are very crucial in the reconstruction and restoration of SR images. In our work we have an optical sensor that is mounted on an unmanned airborne vehicle (UAV) and captures a set of images that contain sufficient overlapped area required to reconstruct a SR image. Due to the wind, The UAV may encounter rotational effects such as yaw, pitch and roll which can distort the acquired as well as processed images with shear, tilt or perspective distortions. In this paper we propose a hybrid algorithm to register these UAV images within subpixel accuracy to feed them in a SR reconstruction step. Our algorithm consists of two steps. The first step uses scale invariant feature transform (SIFT) to correct the distorted images. Because the resultant images are not registered to a subpixel precision, the second step registers the images using a fast Fourier transform (FFT) based method that is both efficient and robust to moderate noise and lens optical blur. Our FFT based method reduces the dimensionality of the Fourier matrix of the cross correlation and uses a forward and backward search in order to obtain an accurate estimation of the subpixel shifts. We discuss the relation between the dimensionality reduction factors and the image shifts as well as propose criteria that can be used to optimally select these factors. Finally, we compare the results of our approach to other subpixel techniques in terms of their efficiency and computational speed.

8399-02, Session 1

Confidence measures of optical flow estimation suitable for multiframe superresolution

A. V. Kanaev, U.S. Naval Research Lab. (United States)

Multi-frame super-resolution of images containing complex motion fields remains an elusive target requiring precise estimation of such motion between the frames. Although accuracy of optical flow algorithms has been increasing steadily it is not yet sufficient to provide confident subpixel resolution enhancement during super-resolution reconstruction. One way to approach the problem is to augment optical flow estimation input into super-resolution procedure by reliable confidence measure. Numerous optical flow confidence or conversely uncertainty measures have been developed recently. However, their performance has been studied and evaluated with respect to error metric involving optical flow vectors, namely angular and end point errors averaged over the entire image. Super-resolution processing requires consideration of interpolation error i.e. the difference between the reference image and the image warped according the optical flow estimation. Additionally, the average error value is not important because relative optical flow confidence across the image is the key. Thus, confidence measures have to be assessed based on their correlation with ground truth and not on the previously used mean error value comparison. This work presents comparative evaluation of optical flow confidence measures based on such correlation of interpolation error and makes conclusions of their usefulness to super-resolution. State-of-art optical flow algorithms based on functional minimizations are considered.

8399-03, Session 1

Precise local blur estimation based on the first-order derivative

H. Bouma, J. Dijk, A. W. M. van Eekeren, TNO Defence, Security and Safety (Netherlands)

Blur estimation is an important technique for many practical applications, such as super resolution, image restoration, turbulence mitigation, deblurring and autofocus. Many techniques have been proposed to perform blur estimation in images and video. In a short survey, we show that some are computationally intensive, and some are easily deteriorated by the response of neighboring edges. Some seem very efficient and robust, but they have large stochastic errors when computed close to the edge location and biased estimates at other locations, as will be shown and analyzed.

In this paper, we present an efficient, accurate and precise blur estimator that can be computed at the edge location. Furthermore, it is robust against small variations due to dislocation or noise. The novel estimator is based on the first-order derivative. Our method is compared and benchmarked against previous state-of-the-art under different levels of blur, dislocations and noise to gain insight in the robustness. The capabilities and limitations of each of the methods are analyzed and described. The experimental results show that the presented method is fast, unbiased and with low stochastic error.

8399-04, Session 1

Compressive imaging measurement design from an image patch manifold prior

R. R. Muise, Lockheed Martin Missiles and Fire Control (United States)

We look at the design of projective measurements based upon image priors. If one assumes that image patches from natural imagery can be modeled as a low rank manifold, we develop an optimality criterion for a measurement matrix based upon separating the canonical elements of the manifold prior. Any sparse image reconstruction algorithm has improved performance using the developed measurement matrix over using random projections. Some insights into the empirical estimation of the image patch manifold are developed and several results are presented.

8399-05, Session 1

Fast stochastic Wiener filter for superresolution image restoration with information theoretic visual quality assessment

A. H. Yousef, J. Li, M. A. Karim, Old Dominion Univ. (United States)

Super-resolution (SR) refers to reconstructing a single high resolution (HR) image from a set of subsampled, blurred and noisy low resolution (LR) images. The reconstructed image suffers from degradations such as blur, aliasing, photo-detector noise and registration and fusion error. Wiener filter can be used to remove artifacts and enhance the visual quality of the reconstructed images. In this paper, we introduce a new fast stochastic Wiener filter for SR reconstruction and restoration that can be implemented efficiently in the frequency domain. Our derivation depends on the continuous-discrete-continuous (CDC) model that represents most of the degradations encountered during image-gathering and image-display processes. We incorporate a new parameter that accounts

for LR images registration and fusion errors. Also, we speeded up the performance of the filter by constraining it to work on small patches of the images. Beside this, we introduce four figures of merits: information rate, theoretical minimum data rate, information efficiency, and maximum realizable fidelity, which can be used to assess the visual quality of the resultant images. Simulations and experimental results demonstrate that the derived Wiener filter that can be implemented efficiently in the frequency domain can reduce aliasing, blurring, and noise and result in a sharper reconstructed image. Also, Quantitative assessment using the proposed figures coincides with the visual qualitative assessment. Finally, we evaluate our filter against other SR techniques and its results were very competitive.

8399-06, Session 2

An adaptive segmentation technique for automatic object region and boundary extraction for human activity recognition

F. A. Albalooshi, V. K. Asari, Univ. of Dayton (United States)

An unsupervised adaptive segmentation technique based on an active contour model for automatic object region and boundary extraction in video sequences is proposed. The active contour model identifies each region using certain region descriptors that guide the motion of the initial contour towards the actual region of interest. The region descriptors depend on the statistical information inside and outside the initial contour, which control the growth or contraction of the contour. A process of selective binary and Gaussian filtering regularization level set smooths the level-set function in order to maintain the level of expansion of the active contour. The adaptivity of the proposed method comes from automatic selection of an optimal Gaussian filter parameter which depends on the characteristics of the input video frames. More precisely, the algorithm utilizes the statistical information of each video frame to identify the optimal value of the Gaussian parameter which should be large enough to cover most of the level-set function, but not too large to overlap multiple neighboring objects. The optimal value of Gaussian parameter affects the segmentation performance of the entire human activity video sequence. The performance of the proposed method was tested and evaluated on Weizmann human activity data base and the KTH research project database which represent object regions in different illuminations and scenarios. The performance of the proposed method is also compared to several state-of-the-art image segmentation methods and observed improved results in terms of accuracy and efficiency. The study demonstrates the robustness of the method to non-uniform illuminations and background noises.

8399-07, Session 2

A novel approach to detect active regions in the solar dynamics observatory images of the sun

S. Suresh, R. R. Dube, C. M. Glenn, Sr., Rochester Institute of Technology (United States)

Solar images taken at different wavelengths enable scientists to visualize and analyze the suns activities. The solar dynamics observatory provides high-resolution images of the sun taken at approximately every second at varying wavelengths, resulting in finely detailed and almost continuous data for researchers examination. Active regions of a sun are regions with high magnetic field and generally are relatively bright regions in the solar image. We propose an approach to find active regions that involve a partial differential equation based noise removal, shifted means based segmentation, and voting based edge linking to link fragments. The above approach does not blur out edges of the active region and gives a good-segmented image of the active region. We use images taken at different wavelengths to evaluate the results. This method is capable of laying foundations on analysis of various other features of the sun like detection of coronal holes and prominences.

8399-09, Session 3

Tracking individuals in surveillance video of a high-density crowd

N. Hu, TNO Defence, Security and Safety (Netherlands) and Univ. van Amsterdam (Netherlands); H. Bouma, TNO Defence, Security and Safety (Netherlands); M. Worring, Univ. van Amsterdam (Netherlands)

Video cameras are widely used in surveillance applications to monitoring public areas, such as train stations, airports and shopping centers. When crowds are dense, automatically tracking individuals becomes a challenging task. In this paper we propose a new tracking technique designed to meet these challenges.

Our tracker employs a particle filter tracking framework. Instead of using a fixed pre-defined state transition model, we employ optical-flow to estimate state transition. Since optical-flow vectors are observed cues from the scene, they provide higher accuracy than the fixed models. In our method, the optical flow vectors are measured over the scene and quantized within local spatial-temporal regions. When the state transition starts, the region containing the particle is employed as the state transition model.

In our tracker, there is no training process required. Training over a long duration of video may result in a less relevant model for tracking, especially for abnormal motions. Thus in our approach, the local region is employed directly for state transition and contains a short duration only. In this way, flow vectors captured in the local region are the most relevant for tracking.

To test the robustness of our tracker, in the paper, the performance is analyzed over separate tracking challenges, such as ambiguous appearance, abnormal pedestrian behaviors, partial occlusion and different density of crowds. Our result shows that the proposed tracker performs better on these challenges and the performance is largely improved compared with the state-of-the-art trackers.

8399-10, Session 3

Sparse coding for hyperspectral images using random dictionary and soft thresholding

E. Oguslu, J. Li, Old Dominion Univ. (United States)

Many techniques have been recently developed for classification of hyperspectral images including support vector machines (SVMs), neural networks, graph-based methods, border vector detection method and AdaBoost. To achieve good performances for the classification, a good feature representation of the hyperspectral images is essential. Many feature extraction algorithms have been developed such as principal component analysis (PCA) and independent component analysis (ICA). Sparse coding has recently shown state-of-the-art performances in many computer vision applications including image classification. In this paper, we have implemented one of the sparse coding techniques for hyperspectral image classification by decoupling the feature sparse coding into a training and an encoding steps. In the training step, we randomly selected a large number of 20-dimensional vectors (patches) from hyperspectral images as dictionary. A soft threshold activation function was then utilized in the encoding step to achieve a sparse representation for the hyperspectral images. We applied the proposed algorithm to a hyperspectral image dataset collected at the Kennedy Space Center (KSC) and compared our results with those obtained by a recently proposed method, supervised locally linear embedding weighted k-nearest-neighbor (SLLE-WkNN) classifier. We have achieved state-of-the-art performances on this dataset with an overall accuracy of 95.30%, which is better than that by the SLLE-WkNN classifier (93.05%). We conclude that this simple feature extraction framework might lead to more efficient and competitive hyperspectral image classification systems.

8399-11, Session 3

Low-power, autonomous, remote-sensor units using the latest advances in silicon-based neural network computing

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There is an ever increasing need for low power, autonomous, remote sensor units to monitor the environment across many different modalities (motion detection, shape recognition, acoustic or electromagnetic signatures) to detect, classify and communicate anomalies quickly and efficiently. Current solutions are typically power and bandwidth intensive as they expend the vast majority of their operating life monitoring steady-state, normative conditions and communicating back to a central computer.

This presentation discusses the application benefits of using low power remote sensor units comprising a sensor, a neural processor and a communication device. The sensor unit is adapted to perform complex pattern recognition via the neural processor and to transfer the result of the pattern recognition via the communication device.

The key to a successful design is to have sensor operate as autonomously as possible. This is achieved using the latest advances in silicon-based neural network computing to create a low-power, extremely fast decision-making engine. Our decision-making engine uses associative memory structure based on artificial intelligence for highly non-linear classification of patterns that are performed in a context sensitive decision. Thus, steady-state, “normal” conditions are ignored by the sensor and only anomalies are reported via mesh network or directly via wireless communication (GSM, UMTS, FM, etc.) Our silicon-based neural computing (rather than software-based) units can be powered via battery charged from small solar arrays and have the added benefit of being field upgradable via remote, allowing monitoring personnel to continually improve detection, classification and sensor unit communication.

8399-12, Session 3

Similarity measures versus change detection algorithms in hyperspectral imagery

S. Adar, Y. Shkolnisky, E. Ben-Dor, Tel Aviv Univ. (Israel)

Change detection (CD) algorithms for Hyperspectral Remote Sensing (HRS) data have been used for many application fields, such as environmental monitoring and security purposes. Although change detection algorithms (CDA) have greatly improved in terms of quality of the results, their application still requires significant computational resources, thus limiting their applicability. In this paper we examine performance tradeoffs between more complex change detection approaches and relatively simple similarity measures. The task used for assessing these tradeoffs was the identification of changes on a large multi-strip mosaic data set, while still maintaining acceptable processing power requirements for these needs. The data set for this purpose was two HyMap images acquired over the same lignite open-pit mining site in Sokolov, Czech Republic, during the summers of 2009 and 2010 (9 and 7 strips respectively). The site selected for this research is one of three test sites (the others being in South Africa and Kyrgyzstan) within the framework of the EO-MINERS FP7 Project (http://www.eo-miners.eu). The change detection algorithms that have been tested include Linear Chronochrom (LCC), Covariance Equalization (CE), Principal Component Analysis (PCA), and Multivariate Alteration Detection (MAD). As similarity measures, we have been using Spectral Angle Mapper (SAM), Spectral Information Divergence (SID), Euclidean Distance (ED) and Spectral Correlation Measure (SCM).

8399-13, Session 3

Human action recognition using body signature and hidden Markov model

K. Chou, C. Hsieh, Tatung Univ. (Taiwan)

This paper presents a human action recognition system based on Hidden Mrkov Model (HMM). Body contour signature and skeleton features are extracted and merged as the feature vector used to describe a human action. In our proposed system, each of the six defined human actions is decomposed into a sequence of basic postures. We design a codebook containing all the basic postures and their corresponding feature vectors. Each feature vector of the input image is matched against the codebook and is assigned to the basic posture with the largest similarity. By this way, time-sequential images are transformed into a symbol sequence. HMM is used to train each action type. In the learning phase, the parameters of HMM are optimized so as to best describe the action sequence. For action recognition, the type of HMM that is best matched with the input sequence is chosen as the recognized action type. We have implemented the human action recognition system based on our approach and have tested the system performance. The system is capable to recognize six distinct actions. The used images are separated into two sets, the training set and the testing set. Training set contains each type of the six actions performed 10 times by a person for building the HMMs. Testing set contains all the defined actions performed 10 times by eight persons. The average recognition rate is 92.9% which shows that the action models trained from a restricted data set provide sufficient capability to recognize these actions with variations.

8399-14, Session 4

Multiplatform GPGPU implementation of the active contours without edges algorithm

O. Zavala-Romero, A. D. Meyer Baese, The Florida State Univ. (United States)

An OpenCL implementation of the Active Contours Without Edges algorithm is presented. The proposed algorithm uses the General-purpose computing on graphics processing units (GPGPU) to accelerate the original model by parallelizing two main steps of the segmentation process, the computation of the Signed Distance Function (SDF) and the evolution of the segmented curve.

The proposed scheme to compute the SDF is based on the iterative construction of partial Voronoi diagrams of a reduced dimension and obtains the exact Euclidean distance in O(N/p) time, where N is the number of pixels and p the number of processors.

This work is being made as an open source software that, being programmed in OpenCL, can be used in different platforms allowing a broad number of final users. The current software is able to segment objects in videos after an initialisation step and can be applied in different areas of computer vision like medical imaging, tracking, robotics, etc.

8399-15, Session 4

Edge detection with edge pattern analysis and inflection characterization

B. Jiang, National Institute of Aerospace (United States)

In general edges are considered to be abrupt changes or discontinuities in two dimensional image signal intensity distributions. The accuracy of front-end edge detection methods in image processing impacts the eventual success of higher level pattern analysis downstream. To generalize edge detectors designed from a simple ideal step function model to real distortions in natural images, research on one dimensional edge pattern analysis to improve the accuracy of edge detection and localization proposes a RISS edge detection algorithm, which is composed by four basic edge patterns, such as ramp, impulse,

step, and sigmoid. After mathematical analysis, general rules for edge representation based upon the classification of edge types into four categories-ramp, impulse, step, and sigmoid (RISS) are developed to reduce detection and localization errors, especially reducing “double edge” effect that is one important drawback to the derivative method.

But, when applying one dimensional edge pattern in two dimensional image processing, a new issue is naturally raised that the edge detector should correct marking junctions or inflections of edges. Research on human visual perception of objects and information theory pointed out that a pattern lexicon of “inflection micro-patterns” has larger information than a straight line. Also, research on scene perception gave an idea that contours have larger information are more important factor to determine the success of scene categorization. Therefore, inflections or junctions are extremely useful features, whose accurate description and reconstruction are significant in solving correspondence problems in computer vision. Therefore, aside from adoption of edge pattern analysis, inflection or junction characterization is also utilized to extend traditional derivative edge detection algorithm.

Experiments were conducted to test my propositions about edge detection and localization accuracy improvements. The results support the idea that these edge detection method improvements are effective in enhancing the accuracy of edge detection and localization.

8399-16, Session 4

Partial spectral unmixing of hyperspectral data for oil spill detection

J. F. Khan, S. M. A. Bhuiyan, Tuskegee Univ. (United States); M. S. Alam, Univ. of South Alabama (United States)

Linear spectral unmixing is a popular tool for remotely sensed hyperspectral data interpretation and classification. It aims at identifying the spectra of all endmembers in the scene to in order to find the fractional abundances of pure spectral signatures in each mixed pixel collected by an imaging spectrometer. Linear Spectral Unmixing exploits the theory that the reflectance spectrum of any pixel is the result of linear combinations of the spectra of all endmembers inside that pixel and simply solves a set of n linear equations for each pixel, where n is the number of bands in the image. But often the estimation of all the endmember signatures may be difficult due to the unavailability of pure spectral signatures in the original data, or inadequacy of spatial resolution. For such cases, partial unmixing can be used where only the user chosen targets need to be mapped and the unmixing equations are partially solved. Like Complete Unmixing, a pixel value in the output image of partial unmixing is proportional to the fraction of the pixel that contains the target material. In this paper, we study the partial spectral unmixing problem under the light of recent theoretical results published in those referred to areas. Our experimental results are conducted using real hyperspectral data sets collected by the NASA Jet Propulsion Laboratory’s Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and spectral libraries publicly available; indicate the potential of partial unmixing techniques in the task of accurately characterizing the mixed pixels using the library spectra. Furthermore, we provide a comparison of complete spectral unmixing and partial spectral unmixing for the oil spill detection in the sea.

8399-17, Session 4

Automatic road extraction from remote sensing images based on a Hessian matrix

Y. Bae, J. H. Jang, J. B. Ra, KAIST (Korea, Republic of)

The road network is one of the most important types of information in the Geographic Information System (GIS). However, automatic extraction of roads is still considered a challenging problem. In this paper, we focus on robust extraction of main roads. In the proposed algorithm, we first determine the roadness of each pixel using the eigenvalues of its Hessian matrix. The roadness represents the belongingness of a pixel to a road; and its determination is performed on a multi-scale basis so that it is robust to various widths of road. We then perform directional grouping to the determined roadness map and remove outliers in each group via size testing and ellipse fitting. Finally, we determine roads by combining the results from each group. Experimental results show that the proposed algorithm can automatically extract most main roads in various remote sensing images.

8399-29, Poster Session

End-to-end image quality assessment

J. Raventos, Nightline, Inc. (United States)

For decades, image quality benchmarking used several types of monochromatic resolution charts which included either bars or alphanumeric symbols (optotypes). Those charts were high contrast, static and predetermined, namely the position of a particular bar or optotype was predictable by an experienced observer after few trials, in addition the time allowed to ascertain features of a particular bar or optotype was unlimited.

An innovative computerized benchmarking approach (US Patent pending) based on extensive application of photometry, geometrical optics and digital media using a randomized target, for a standard observer to assess the end-to-end image quality of video imaging systems, at different day time and low-light luminance levels. It takes into account, the target’s contrast sensitivity and its color characteristics, as well as the observer’s visual acuity and dynamic response. It includes human vision as part of the “extended video imaging system” (EVIS) and allows image quality assessment by several standard observers simultaneously.

This paper describes a new approach for benchmarking the image quality generated by different video systems and how an unbiased assessment can be guaranteed.

Manufacturers, system integrators and end users will have the option of simultaneous group evaluation of end-to-end video imaging systems whether on the field or in the laboratory by simulating a choice of different color, luminance, and dynamic conditions.

8399-30, Poster Session

Novel multiplexed coaxial holographic storage technique

P. S. Chung, City Univ. of Hong Kong (Hong Kong, China); W. Jia, Shanghai Institute of Optics and Fine Mechanics (China); Z. Chen, T. Chung, J. Wen, Y. T. Chow, City Univ. of Hong Kong (Hong Kong, China)

We propose here a novel multiplexed coaxial holographic storage technique using a single-beam system, in which the reference beam and the object beam are bundled in a single beam. In this paper, a spatial light modulator based on a high-resolution twisted nematic liquid crystal display to record both reference and object beams. We have programmed the active region of the SLM, so that some part will work in the phase modulation mode and some part will work in the amplitude modulation mode. In our coaxial holography design, the central ring area is reserved for amplitude modulation of the object beam while the outer rings/annuli will cater for various phase modulation of the reference beams for multiplexed storage. A number of objects can then be stored/encoded in the same location of the hologram and later be reconstructed using the appropriate reference beams.

Before the experimental demonstration, we have simulated the holographic recording and retrieving processes on the computer. A commercial “FRESNEL” software program has been employed to simulate the storage/coding technique in the scalar field based on Fresnel diffraction approximation. Three different methods of modulating the reference beam are investigated, viz. the diffraction of blaze grating, the diffusion of random speckle and beam shaping.

The coaxial multiplexing holographic data encoding and reconstruction are carried out experimentally in a single-beam 4-f setup using He-Ne laser with a wavelength of 632.8nm. A 2-D holographic medium is used for recording and the reconstructed images are captured by a camera on the image plane. From the results obtained, it can be seen that all the images are reconstructed clearly and separately, demonstrating the feasibility of our proposed novel technique of multiplexed storage/encoding in a single beam.

8399-32, Poster Session

Spatially adaptive defogging for enhancement of color and visibility of UAV image

I. Yoon, H. Kim, J. Im, Chung-Ang Univ. (Korea, Republic of); J. Bae, S. Lee, Hanwha Corp. (Korea, Republic of); J. Paik, Chung-Ang Univ. (Korea, Republic of)

In most practical image the light reflected from a surface is scattered in the foggy space before it reaches the camera. Therefore, the original color of an object turns into a different on which is associated with fog in the space. The direct attenuation describes the decayed version of fog-free image in the medium or space, while the airlight term results from scattering by fog and color shifts. Therefore the goal of the defogging algorithm is to recover fog image, atmospheric light, and luminance map, given defog image.

We present a novel single image-based defogging algorithm. The proposed algorithm first generates the normalized image using the maximum value among all each RGB color channels. Atmospheric light is estimated by using the reflectance of the image, and the luminance map [2] is then generated from the Y channel of the foggy image acquired by the UAV. Based on the estimated atmospheric light and the luminance map, we can remove fog in the spatially adaptive manner.

The proposed algorithm can remove foggy components better than existing techniques because the luminance is additionally analyzed as well as color components. Consequently, the proposed method can improve the visibility of foggy UAV images without color distortion. The proposed algorithm can be applied to enhance foggy images acquired by UAVs, mobile imaging devices, or other consumer digital cameras.

8399-33, Poster Session

Robust 3D model tracking system for intelligent video surveillance

K. H. Bae, Y. Kim, S. Yang, D. Lee, SK Telecom (Korea, Republic of)

In this article, robust 3-D model tracking system about suspicious people for intelligent video surveillance is proposed. In the proposed method, 3-D model tracking is performed based on robust characteristics of an object, such as its motion, shape, and color. Elements of metadata and the optimal tracking method are selected at each frame. Because the characteristics of an object are affected by the camera position and by environmental conditions, a tracking method between individual cameras is selected by means of the optimal metadata. Additionally, the time-sequential disparity-motion vector can be estimated from the feature matching method, which is extracted from the sequence of the stereo images, and metadata sequences. Using this 3-D modeling information, the area where the target object is located and its location coordinate are then detected from the 3-D images. In an experiment, the proposed system is shown to be robust for nonrigid objects and demonstrates its ability to track a target object adaptively with an average low error ratio of approximately 3.17% between the detected and actual location coordinates of the target object.

8399-18, Session 5

Ghost-free high dynamic range imaging using layered exposed images based on local histogram equalization

J. Im, H. Kim, T. Kim, Chung-Ang Univ. (Korea, Republic of); S. Lee, J. Bae, Hanwha Corp. (Korea, Republic of); J. Paik, Chung-Ang Univ. (Korea, Republic of)

In this paper, we present a novel high dynamic range (HDR) imaging method using a single input image. Conventional multiple image-based HDR methods are successful only on condition that there is no motion between the camera and objects motion during the acquisition of multiple, differently exposed low dynamic range (LDR) images. If these constraints are not satisfied, a ghost artifact is produced in the resulting HDR image. In order to overcome these limitations, we generate multiple, differently exposed LDR images from a single input image. We call these multiple images a set of layered exposed images (LEIs). In order to generate an appropriate set of LEIs, we first divide the whole intensity range into multiple sub-ranges using the weighted histogram separation (WHS) method, and then stretch each sub-range so that its histogram is equalized from the minimum to the maximum of the whole intensity range. We also present a novel denoising algorithm for the lower-exposed image in the set of LEIs, which is particularly subject to low light level noise. Given a set of LEIs, we perform weighted fusion to produce the resulting HDR image, which is inherently free from ghost artifacts since all LEIs are geometrically identical. We will present experimental results using the proposed algorithm to extend the dynamic range of unmanned aerial vehicle (UAV) images. The experimental result shows that the proposed method outperforms the existing algorithm in the sense of both removing ghost artifacts and enhancement of image contrast.

8399-19, Session 5

Scene-based, nonuniformity correction in infrared videos

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Recent infrared sensors mostly have a focal-plane array (FPA) structure. Non-uniform response of a FPA structure, however, introduces unwanted fixed pattern noise (FPN) to an IR image. Various non-uniformity correction (NUC) techniques have been developed to alleviate the FPN. They can be categorized into reference-based and scene-based approaches. In order to deal with a temporal drift, however, a scene-based approach is needed. Among the scene-based algorithms, recent conventional algorithms compensates only for the offset non-uniformity of IR camera detectors based on the global motion information. Local motions in a video, however, can introduce inaccurate information for NUC. Therefore, by considering global and local motions simultaneously, we propose a joint correction algorithm of gain and offset. Experiment results using simulated and real IR videos show that the proposed algorithm provides performance improvement on the FPN reduction.

8399-20, Session 5

Infrared image denoising by nonlocal means filtering

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The recently introduced non-local means (NLM) image denoising technique broke the traditional paradigm according to which image pixels are processed by their surroundings. NLM denoising method introduced the concept that any noisy pixel, located in the center of an image patch,

may be denoised by building relevant statistics from patches with similar structure that may be located anywhere in the image. The pixel is filtered by proper averaging with pixels located anywhere in the image having similar surroundings. Non-local mean technique was demonstrated to outperform state-of-the art denoising techniques when applied to images in the visible. This technique is even more powerful when applied to low contrast images, which makes it tractable for denoising infrared images. In this work we investigate the performance of NLM applied to infrared images. First, we will demonstrate how to set the optimal parameters for the NLM filtering. Second, we compare NLM to other state of the art denoising techniques.

In this work we also present a new technique designed to speed-up the NLM filtering process. The main drawback of the NLM is the computational time required by the process of searching similar patches. Several techniques were developed during the last years to reduce the computational burden. Here we present a new techniques designed to reduce computational cost and sustain optimal filtering results of NLM technique. We show that the new technique, which we call multi-resolution search NLM (MRS-NLM), reduces significantly the filtering process and we present a study of its performance on IR images.

8399-21, Session 5

Adaptive smoothing in real-time image stabilization

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Although real-time image stabilization has become a common technology in recent years, it is still rare to find a commercial stabilizer that requires little control but compensates jitter motions covering low to high frequencies and effectively separates camera jitter from the pan motion. There are even fewer that well balances between black border artifacts and stabilization in large motion. Often several options are provided for users to select between slow motion and fast motion and least black border or most stabilized. Furthermore, to avoid black border, a common technique is to zoom in the stabilized image which sacrifices the perimeter of the source image. Our paper addresses these problems and discusses an adaptive smoothing method that balances black border and stabilization, pan and jitter motion. In our approach, the camera pan is first separated from the jitter. A virtual anchor reference frame follows the pan motion. The jitter motion is then compensated in the final display. In order to minimize the black border, An Infinite Impulse Response (IIR) filter is used to smooth the pan and jitter motion respectively. The degree of smoothness is adapted to the residue pan and amplitude of the jitter. The display image is not scaled and thus perimeter is preserved.

The proposed method has been implemented on a TI DSP that runs 30Hz NTSC/PAL video. The system has no external control and has been tested and evaluated in fasting moving vehicles, high towers, UAVs and ships.

8399-22, Session 6

Surface reconstruction for 3D remote sensing

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This research examines the performance of the Local Level Set Method on the surface reconstruction problem for unorganized point clouds in 3D. Many laser-ranging, stereo, and structured light devices are producing 3D information in the form of unorganized point clouds. The point clouds are a sampled representation of closed, water-tight objects in the camera field of view. The reconstruction of these objects in the form of a triangulated geometric surface is an important step in computer vision and 3D image processing. The local level set method uses a Hamilton-Jacobi PDE to describe the motion of a surface in 3-space. An initial surface which encloses the data is allowed to move until it becomes a smooth fit of the unorganized point data. A 3D point cloud test suite was constructed from publicly avaiable laser-scanned object databases and from a 3D Flash LADAR camera. The test suite exhibits nonuniform sampling rates and different noise characteristics to challenge the surface reconstruction algorithm. Accuracy and efficiency of the surface reconstruction algorithm is measured on the degraded data. The results of this research characterize the challenges and potential solutions for surface reconstruction applied to 3D remote sensing.

8399-23, Session 6

Dense point-cloud creation using superresolution for a monocular 3D reconstruction system

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We present an enhanced 3D reconstruction algorithm designed to support an autonomously navigated unmanned aerial system (UAS). The algorithm presented focuses on the 3D reconstruction of a scene using only a single moving camera. In this way, the system can be used to construct a point cloud model of its unknown surroundings. The original reconstruction process, resulting with a point cloud was computed based on feature matching and depth triangulation analysis. Although dense, this model was hindered due to its low disparity resolution. As feature points were matched from frame to frame, due to the discrete nature of disparities the resolution of the input images limited the depth computations within a scene. With the addition of the preprocessing steps of nonlinear super resolution and barrel distortion correction, the accuracy of the point cloud which relies on precise disparity measurement and undistorted video input has significantly increased. Using a pixel by pixel approach, the super resolution technique computes the phase congruency of each pixel's neighborhood and produces nonlinearly interpolated high resolution input frames. Thus, a feature point travels a more precise discrete disparity. Also, the quantity of points within the 3D point cloud model is also significantly increased since the number of features is directly proportional to the resolution and high frequency of the input. The contribution of the newly added preprocessing steps is measured by evaluating the density and accuracy of the reconstructed point cloud for autonomous navigation and mapping tasks within unknown environments.

8399-24, Session 6

A study of the sensitivity of long-range passive ranging techniques to atmospheric scintillation

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Optical ranging techniques, can be broadly classified as either active or passive. The former emit energy into the scene and are able to get high precision measurements but in doing so sacrifice their covertness. Passive ranging techniques are thus desirable in a number of situations, but tend to be both more computationally complex and less accurate.

This work aims to determine the sensitivity of monocular passive ranging techniques to atmospheric scintillation in uncontrolled outdoor environments for ranges up to 1km. This is applicable to many applications including surveillance, border control, artillery and autonomous navigation of ground vehicles. Atmospheric turbulence degrades images in two primary ways (Robinson 2010): quasi periodic motion within the image and localised non-uniform blurring. Both of these effects vary over time and have been - together with their mitigation - the subject of much research (Aboola 2010, Robinson 2010, Delport 2010).

Multi camera approaches such as stereo vision are not investigated in this work due to the difficulty of determining the relative 6 degree of freedom positions of cameras that have a sufficiently wide baseline to obtain accurately triangulated ranges of 1km. A sampling of depth from

defocus ranging techniques, from Pentland's original implementation (Pentland 1987) to space variant approaches (e.g. Subbarao 1992) and rational filter methods (e.g. Watanabe) are compared to depth from focus techniques. Several image sharpness metrics for depth from focus ranging are investigated including the standard deviation and entropy of the regions of interest. The closest related work to this is Cozman's work on depth from scattering (Cozman 1997) which attempts to use the blue shift induced by aerosol scattering to determine distance to far objects. This was done at high latitudes where scintillation is not a dominant factor. The technique also requires spectral reflectance of the target and sensitivity of the receiver, which can not be determined using the gray scale cameras employed in this work.

A selection of long focal length, large aperture cameras were used to observe high contrast targets that were placed at known distances on level terrain. Both the camera and the targets were placed closed to the ground to maximise the effect of the turbulent atmosphere. A scintillometer was used to quantify the amount of scintillation induced by the atmosphere to each target for each measurement. Multiple measurements were captured at various times of day to get a wide gamut of samples across the scintillation-distance spectrum. These were compared to the ground truth target distances to determine how the different calculated ranges were affected by the atmospheric turbulence.

An attempt to improve the accuracy and decrease the sensitivity of the ranging techniques was performed by employing techniques (Delport 2010) to de-warping the recorded data and lessen the quasi periodic image motion. The results of these preliminary tests are compared to the raw results. Finally, a discussion of the results of the different techniques is followed by findings regarding the best performing combination of ranging and mitigation techniques to use for no, mild and severe scintillation.

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8399-25, Session 6

A method for 3D scene reconstruction using shadow information and a single fixed viewpoint

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The ability to passively reconstruct a scene in 3D provides significant enhances to situational awareness systems employed in security and surveillance applications. Traditionally, passive 3D scene modelling techniques, such as shape from silhouette, require images from multiple sensor viewpoints, acquired either through the motion of a single sensor or from multiple sensors. As a result, the application of these techniques often attract high costs, and present numerous practical challenges. This paper presents a 3D scene reconstruction approach, based on exploiting scene shadows, which only requires information from a single static sensor. The paper demonstrates that a large amount of 3D information about a scene can be interpreted from shadows; shadows reveal the shape of objects as viewed from a solar perspective - additional perspectives are gained as the sun arcs across the sky. The approach has been tested on synthetic and real data and is shown to be capable of reconstructing 3D scene objects where traditional 3D imaging methods fail. Providing the shadows within a scene are discernible, the proposed technique is able to reconstruct 3D objects that are camouflaged, obscured or even outside the sensor's field of view. The proposed approach can be applied in a range of applications, for example urban surveillance, checkpoint and border control, critical infrastructure protection and for identifying concealed or suspicious objects or persons which would normally be hidden from the sensor viewpoint.

8399-26, Session 7

Mean squared error performance of MFBD nonlinear scene reconstruction using speckle imaging in horizontal imaging applications

G. E. Archer, J. P. Bos, M. C. Roggemann, Michigan Technological Univ. (United States)

Terrestrial imaging along long horizontal paths is increasingly common in surveillance and defense systems. All optical systems that operate in or through atmospheres suffer from turbulence induced image blur. A variety of techniques have been employed to reconstruct the common object that gives rise to a set of speckle images using multi-frame blind deconvolution. This paper explores the Mean-Square-Error performance of a multi-frame blind deconvolution-based reconstruction technique using a non-linear optimization strategy to recover the Zernike-polynomial coefficients. These polynomial coefficients are then used to determine the phase errors in the optical transfer function, and ultimately a reconstructed object. Three sets of 70 images representing low, moderate and severe turbulence degraded images were simulated from a diffraction limited image taken with a professional-consumer digital camera. MFBD reconstructed objects showed significant improvement in Mean Squared Error for low and moderate atmospheric turbulence. A parametric study of the number of frames required and the number of Zernike polynomial terms necessary is described with recommendations for how to use this technique.

8399-27, Session 7

A new MTF compensation algorithm based on Wiener filter and Richardson-Lucy algorithm

J. Lee, J. Chun, KAIST (Korea, Republic of); D. Lee, Korea Aerospace Research Institute (Korea, Republic of)

The republic of Korea is developing a new earth observing satellite to collect electro-optical image data. Due to the operating condition of the Satellite the measured point spread function (PSF) is spatially variant hence a new algorithm applicable to spatially variant PSF and able to process Modular Transfer Function (MTF) compensation is required.

For image restoration of the blurred image the Wiener filter is known to be an optimal filter from the linear mean square (LMS) sense, estimating the desired noiseless image giving a good performance in noise suppression but attenuating the useful information at the same time. For deconvolution application of spatially-variant PSF, Richardson Lucy (RL) algorithm is often applied which estimates maximum likelihood solution of desired image for each iteration. However it conveys undesirable noise amplification, common issues of maximum likelihood problem and also shows loss of local information represented as ringing artifacts around sharp edges of the object in the image. Based on RL algorithm in combination with Wiener filter a new deconvolution algorithm has developed to recover the lost information from RL algorithm and compensate the problems caused by Wiener filter simultaneously. Two algorithms are applied in turns hence the visible ringing at each iteration of RL algorithm is recovered by Wiener filter before processed for the next. The deconvoluted image shows improvement in removing ringing artifacts compared to using RL algorithm.

8399-28, Session 7

A comparison of some predictors of stereoscopic match correctness

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Previously we introduced the concept of continuous quantification of uniqueness, as a general purpose technique designed to be applicable to any situation in which there is a need to decide which of several equally effective objects to choose for a task, that requires recognition of the chosen object, in a variety of contexts, by comparing attributes which contain a non trivial amount of context dependent variability. We defined that uniqueness assessment as an algorithm that computes a fuzzy set membership function that measures some but not all aspects of the probability that the sought after object will not be confused with other objects in the space being searched. We evaluated the usefulness of that concept by experimentally assessing the extent to which the uniqueness of the global minimum of locally computed image subset dissimilarity was both a predictor of bidirectional match compliance with the Epipolar Constraint, and a predictor of bidirectional match disparity correctness, for the classic stereoscopic correspondence problem of computer vision, and in that context found the uniqueness of the aforementioned global minimum to be a useful but imperfect predictor of success. In this paper we compare the usefulness of the uniqueness of the aforementioned global minimum to that of, the magnitude of that same global minimum, the magnitude of variability across contributors to that global minimum, uniqueness of that variability, and co-occurrence of the global minimum of local image subset dissimilarity and global minimum of variability across contributors to local image subset dissimilarity.

8399-31, Poster Session

Quantifying focus criterion function comparison for two-stage autofocusing system

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To obtain high speed and accuracy, two-stage searching strategy has been widely applied in autofocusing system of microscopy. The first stage aims at searching the rough focus position with high speed, while the second stage aims at reaching the accurate focus position in the premise of the first-stage searching. Both stages need to analyze images using appropriate focus criterion functions, which affect the efficiency and accuracy of the autofocusing system seriously. To select the optimal focus criterion function, many researches have been done in the analysis the numerous focus algorithms. However, current major analysis and selection works are applicable to the second searching stage while ignoring the first stage. In order to help choose the best algorithm, this paper is aimed at proposing the ranking methodology for focus criterion functions in both stages in autofocusing system. The ranking methodology for the first stage is proposed for the first time and the second one is improved based on previous works. The synthetic defocused images are simulated from high definition images by Gaussian filter according to the defocus imaging principle. To achieve more realistic defocused images, noise of different ranges is added to image sets. The proposed ranking methodology for algorithm performance are introduced and then tested on the image sets above, and the result shows the gap of performance among them. Finally, to verify the effectiveness of the new ranking methodology, the practical autofocusing system is built up and real defocused images are captured to evaluate the same algorithms, the result of which matches the evaluation on synthetic image sets.

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8400-01, Session 1

Probing correlation in quantum arrays

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The physical state of quantum systems in engineered arrays, such as that of qubits in a register in a quantum computer, may degrade by a variety of noise processes. Because of shared components or simple physical proximity, the local degradations at the different array elements may be correlated. This correlated noise process can be modeled by parallel quantum channels with a correlation parameter, and estimating this parameter can be expected to be important to the quantum array's design and/or operation. The present work considers whether probes of quantum arrays should be entangled depending upon the degree of correlation. We study quantum arrays with depolarizing noise and compare the quantum Fisher information (QFI) available about the array's noise correlation from probes in a pure product state with that available from probes in a maximally entangled Greenberg-Horne-Zeilinger (GHZ) state. We analytically treat arrays with any number of elements, elements with any dimension, and any rate of depolarization. One might expect that a GHZ probe state, with its strong quantum correlation, would be better "tuned" to arrays with high noise correlation and that for these arrays a GHZ probe would yield more information about the correlation. We find that this is not the case. The noise correlation matters only secondarily to whether a GHZ probe is advantageous. The choice of probe state is dictated primarily by the depolarizing rate. The relationship between probe correlation and array correlation exhibits a curious transition: for arrays with just a few elements, separable probes tend to yield more information about noise correlation when the noise is low, but less when the noise is high. For more than a few elements, though, this flips and a GHZ probe is advantageous when the noise is low and disadvantageous with high noise. We find the QFI in the limiting cases of infinite arrays and elements with infinite dimensions and obtain results that suggest that correlation estimation in these regimes is in some sense classical in nature.

8400-02, Session 1

The first experimental demonstration of ghost imaging with sunlight

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A recent observation of near-field lensless ghost imaging with sunlight is reported in this article. In addition to its obvious importance in practical applications, sunlight ghost imaging is also important in fundamental concerns: (1) it excludes the "speckle-to-speckle correlation" theory of ghost imaging: sunlight does not have speckles and (2) it supports the multi-photon interference picture for second-order correlation of thermal light, which is helpful in understanding the fundamental aspects of this kind phenomena.

The Fabry-Perot(FP) filter with a certain restricted bandwidth is necessary to observe the second-order correlation of sunlight. By using a FP filter, we are able to overcome that difficulty of getting ghost image with sunlight. The image of a double-slit is observed in terms of coincidence counts between two spatially separated photon counting detectors D1 and D2.

Sunlight ghost imaging is the result of a point-to-point correlation of sunlight. What is the cause behind this point-to-point correlation of sunlight? The classical theory of speckle-to-speckle correlation fails to answer this question. On the hand, the Glauber theory of photo-detection gives a reasonable answer: the sunlight point-to-point image-forming correlation comes from the nonlocal interference which involves the superposition of two-photon amplitudes, corresponding to diffierent yet indistinguishable alternative ways for a random pair of photons to produce a joint photodetection event. As a result of two-photon interference, ghost imaging has three peculiar features:(1) it is nonlocal (2) it achieves higher spatial resolution for long distance imaging, for example, taking a picture of an object in 10km distance, sunlight ghost imaging achieves a spatial resolution equivalent to that of a classical image device with 92m-diameter lens and (3) it has "turbulence-free" nature. These peculiar features are very important and useful in distant imaging applications.

8400-03, Session 1

Manipulations of cold atoms on a chip: double well and 1D bose gas

J. S. Alexander, V. Prieto, C. Rowlett, P. J. Lee, W. M. Golding, U.S. Army Research Lab. (United States)

We report on recent experimental results on manipulating cold atoms trapped on a chip for quantum sensing. The first experiment uses wires on the surface of a lithographically patterned chip to produce a double-well potential intended for splitting a cloud of cold 87Rb atoms. Finite element modeling of different current and bias field configurations indicates a means to coherently split the atomic cloud through dynamically adjusting these experimental parameters. In our experiment, we investigate real-time transformations between different double-well configurations adiabatically and non-adiabatically, and study their effects on the initially trapped atoms. Coherence properties of the two atomic wavepackets are also examined to evaluate their potential use in an atom interferometer. For the second experiment, we investigate the properties of bosons confined to (quasi) one dimension in our magnetic waveguide on the chip. When the atom-atom repulsive interaction becomes much larger than the kinetic energy, bosons confined in one dimension can enter a new state of matter, called the Tonks-Girardeau gas, in which they behave like non-interacting fermions. However, the bosons can still occupy the same momentum state and therefore the gas cannot be fully described by either Bose-Einstein or Fermi-Dirac statistics. This transition has been observed in optical lattices but not yet in magnetic atom chip waveguides. We discuss the conditions for obtaining a Tonks-Girardeau gas with 87Rb atoms in our atom chip waveguide and discuss a novel signature for observing the transition in our system.

8400-04, Session 1

Optical frequency combs for quantum control on atom chips

Q. Quraishi, V. Malinovsky, J. S. Alexander, V. Prieto, C. Rowlett, P. J. Lee, U.S. Army Research Lab. (United States)

Atomic spin trapped on a microfabricated chip can be a valuable resource study atom interferometry, atomtronics, and quantum information processing. Atom chips offer an attractive, compact and robust architecture. Here, we propose a novel scheme to entangle the spin and motion of the atoms confined on an atom chip using optical frequency combs, emitted by an ultrafast modelocked pulsed laser. Pairs of optical comb modes drive stimulated off-resonant Raman transitions between two clock states of 87Rb (separated by 6.8 GHz). This is useful to study effects of atomic interactions when applied to a Bose-Einstein condensate on an atom chip.

8400-05, Session 1

Spectroscopy of a deterministic single-donor device in silicon

M. Fuechsle, J. A. Miwa, S. Mahapatra, The Univ. of New South Wales (Australia); H. Ryu, Korea Institute of Science and Technology Information (Korea, Republic of); S. Lee, Purdue Univ. (United States); L. C. L. Hollenberg, The Univ. of Melbourne (Australia); G. Klimeck, Purdue Univ. (United States); M. Y. Simmons, The Univ. of New South Wales (Australia)

The spin states associated with donors in silicon are a promising candidate for the realization of quantum logic devices due to their resilience against decoherence [1]. As a result, various silicon quantum computer architectures have been proposed [2], using either the nuclear spin, or donor electron spin or charge of individual phosphorus dopants to define the qubit. However, while considerable progress has recently been made towards spin read-out [3], a remaining challenge is the scale-up of donor-based architectures [4] which relies on vast arrays of individual impurities which need to be patterned with essentially atomic precision within the host crystal.

Here, we present a single electron transistor (SET) based on an individual phosphorus donor which is deterministically placed with a spatial accuracy of ±1 lattice site within an epitaxial silicon environment. Low temperature transport measurements confirm the presence of a single donor the charge state of which can be precisely controlled with gate voltages. We show that atomistic modeling can fully capture the effects of the highly-doped transport electrodes on the electronic states of the donor, thus highlighting the high level of control over the electrostatic device properties afforded by a deterministic single donor architecture. The fabrication technique presented here opens the door for novel device concepts which use single dopant atoms as their active elements. In particular, our work presents an important step towards the realization of a scalable donor-based qubit architecture.

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8400-06, Session 1

Phonons in a double-well: transverse vibrations in a pair of trapped ions

P. J. Lee, U.S. Army Research Lab. (United States)

Double-well potentials have extensive applications in many branches of physics and have resulted in devices that are useful for precision sensing as well as quantum information processing. Here, we present theoretical analysis of the transverse phonon coupling between a pair of trapped ions as described by a double-well system. Typically the phonons of trapped ions are used as an intermediary in quantum information processing, but here we focus on the dynamics of the phonons themselves. The double-well system is a special case of the more generalized Bose-Hubbard Model, with exactly two sites available to store particles. We draw an analogy to another double-well system in solid state physics: a Josephson junction containing a thin insulating barrier between two superconductors. Applications of the Josephson junction include superconducting quantum interference devices (SQUIDs), which have emerged as sensitive magnetometers and also as qubits for quantum computation. Another analogy is the recent demonstrations of matter-wave interference with Bose-Einstein condensates in double-well traps, which have also shown great promise for applications in precise inertial and gravitational field sensing. Such comparisons have never been presented in the literature previously, but should be extremely valuable in gaining an understanding of what phonon behaviors can be expected in a trapped ion system and how to control and manipulate such a system.

8400-07, Session 2

Effects of loss and amplification on entangled photon holes

J. D. Franson, Univ. of Maryland, Baltimore County (United States)

The maximum operating range of quantum key distribution systems in optical fibers is currently limited by photon loss and the inability to use amplifiers. Entangled photon holes are a new form of entanglement in which there is a correlated absence of photons in two distant beams of light. A photon is removed from each beam at the same time, but there is a coherent superposition of times at which that may have occurred. This produces an energy-time entangled state that can violate Bell's inequality and may be useful for quantum key distribution. Since the quantum information is carried by the absence of a photon, one might naively expect that entangled photon holes may be less sensitive to photon loss than are entangled pairs of photons. A theoretical analysis shows that entangled photon holes are relatively insensitive to photon loss if the absorbing atoms in the medium have a coherence time that is much longer than the time delay (typically a fraction of a nanosecond) used in nonlocal interferometry. Roughly speaking, the absorbing atoms do not retain any "which path" information regarding the time at which a photon hole passed through the medium in that case. Entangled photon holes can also be amplified under similar conditions with minimal decoherence of the entangled state, aside from the usual amplifier noise.

8400-08, Session 2

LDPC error correction in the context of quantum key distribution

A. Nakassis, A. Mink, National Institute of Standards and Technology (United States)

The Low Density Parity Check (LDPC) error correction mechanism has emerged as a popular option in several communication protocols, including the Reconciliation phase of the Quantum Key Distribution (QKD) protocol. The typical LDPC implementation assumes a single communication channel for data and correction information, whereas QKD has two channels of which the second supports security services and can be assumed to be reliable; as a result, error-correction can be attained with less redundancy than the amount required in classical communications. This paper proposes a lower entropy bound on the information that a potential eavesdropper may gain from the check sum information exchanged during the LDPC algorithm. It describes the underlying environment of LDPC-for-QKD use and presents algorithmic variants that are simple to implement and efficient. Performance data for these variants (such as number of iterations and time needed to converge to a solution) are included.

8400-09, Session 2

Nonorthogonal multistate discrimination strategies outperforming ideal classical receivers

F. E. Becerra, J. Fan, National Institute of Standards and Technology (United States); J. Goldhar, Univ. of Maryland, College Park (United States); J. T. Kosloski, The Johns Hopkins Univ. (United States); A. L. Migdall, National Institute of Standards and Technology (United States)

Maximizing the information successfully received over a communication channel requires optimizing the detection sensitivity of the receiver used. This is a critical issue in the fields of quantum and classical communications. When the information is encoded and transmitted using coherent states, the receiver decodes the information though measurements that discriminate among the possible states. However, it is not possible to discriminate with total certainty among nonorthogonal states such as coherent states. The minimum error probability achievable with ideal conventional receivers is referred to as the standard quantum limit (SQL). However, quantum mechanics allows for measurements that can discriminate with significantly lower error probabilities than the SQL. Besides optimizing strategies to minimize error probabilities for nonorthogonal-state receivers, there is an alternative path towards maximizing the information communicated over a channel. That is, the receiver can implement generalized measurements that allow unambiguous state discrimination (USD) where no errors occur, but at the cost of having some inconclusive measurement results.

We study two strategies for the discrimination of multiple nonorthogonal states performing below the limits for conventional receivers. We experimentally emulate a receiver to investigate an optimized strategy for minimum-error discrimination of coherent states in a quadrature phase-shift keyed (QPSK) format. This strategy allows nonorthogonal multi-state discrimination below the SQL. We study a state discrimination strategy to unambiguously discriminate QPSK coherent states. We quantify the effects of losses and possible component imperfections of a receiver on the unambiguous discrimination process.

8400-10, Session 2

Thwarting the photon number splitting attack with entanglement enhanced BB84 quantum key distribution

C. D. Richardson, C. Sabottke, Louisiana State Univ. (United States); P. Anisimov, Stony Brook Univ. (United States); U. Yurtsever, MathSense Analytics (United States); A. Lamas, National Univ. of Singapore (Singapore); J. Dowling, Louisiana State Univ. (United States)

We develop an improvement to the weak laser pulse BB84 scheme for quantum key distribution, which utilizes entanglement to improve the security of the scheme and enhance its resilience to the photon number splitting attack. This protocol relies on the non-commutation of photon phase and number to detect an eavesdropper performing quantum non-demolition measurement on number. The potential advantages and disadvantages of this scheme are compared to the coherent decoy state solution.

Most entanglement based quantum key distribution schemes rely on violations of Bell's inequalities to ensure security. However, this is not the strategy that our entanglement enhanced (EE) BB84 employs here. Instead, we detect Eve by introducing an entangled quantum state into the system that is sensitive to Eve's QND measurements. This allows for a recovery of an approximately linear dependence on transmittivity for the key rate. EE BB84 shares this advantage with coherent decoy state protocols as well as schemes that utilize strong phase reference pulses to eliminate Eve's ability to send Bob vacuum signals.

8400-11, Session 3

Szilard engine reversibility as quantum gate function

F. M. Mihelic, The Univ. of Tennessee (United States)

A quantum gate is a logically and thermodynamically reversible situation that effects a unitary transformation of qubits of superimposed information, and essentially constitutes a situation for a reversible quantum decision. A quantum decision is a symmetry break, and the effect of the function of a Szilard engine is a symmetry break. A quantum gate is a situation in which a reversible quantum decision can be made, and so if a logically and thermodynamically reversible Szilard engine can be theoretically constructed then it would function as a quantum gate. While the traditionally theorized Szilard engine is not thermodynamically reversible, if one of the bounding walls of a Szilard engine were to be constructed out of the physical information by which it functions in such a manner as to make that information available to both sides of the wall simultaneously, then such a Szilard engine would be both logically and thermodynamically reversible, and thus capable of function as a quantum gate. A theoretical model of the special case of a reversible Szilard engine functioning as a quantum gate is presented and discussed, and since a quantum decision is made when the shutter of a Szilard engine closes, the coherence of linked reversible Szilard engines should be considered as a state during which all of the shutters of linked Szilard engines are open simultaneously.

8400-12, Session 3

Quantum information processing with tapered optical fibers

M. Lai, Univ. of Maryland, Baltimore County (United States); S. M. Hendrickson, The Johns Hopkins Univ. Applied Physics Lab. (United States); T. B. Pittman, J. D. Franson, Univ. of Maryland, Baltimore County (United States)

Our group has been interested in an optical approach to quantum computation and proposed a universal optical quantum logic gate that uses the quantum Zeno effect to prevent errors associated with two photons exiting a device in one mode. These "Zeno Gates" require very strong Two-Photon Absorption (TPA) but very weak single photon absorption (SPA). In addition to Zeno Gates, strong TPA can be also used to realize ultra efficient classical optical switches, and it is a promising tool to develop a new kind of single photon source.

Here we describe a recent experimental observation of two-photon absorption with ultralow power levels of less than 150 nanoWatts. The experiment involves the use of sub-wavelength diameter tapered optical fibers suspended in rubidium vapor.

8400-13, Session 3

Unitary qubit representation of quantum turbulence

G. Vahala, The College of William & Mary (United States); B. Zhang, The Univ. of Texas at Austin (United States); L. Vahala, Old Dominion Univ. (United States); M. Soe, Rogers State Univ. (United States)

Unitary qubit algorithms are developed that give a mesoscopic representation of turbulence in weakly interacting Bose-Einstein condensate gas. The Gross-Pitaevskii equation for the ground state wave function is a Hamiltonian system with the energy subdivided into kinetic, quantum and internal energies. For very small internal energies one finds very short Poincare recurrence times of the initial state, which scale with diffusion ordering in both 2D and 3D BEC systems. Unlike classical turbulence, in which the classical vortex is only a qualitative concept, the quantum vortex is a topological singularity (with density = 0 at the quantum vortex core), exhibiting a branch-point like singularity in the phase of the wave function. Quantum vortex-vortex interactions occur even with no viscosity, unlike classical vortex-vortex interactions which require dissipation. Only 2 qubits/spatial lattice node are needed to develop this mesoscopic representation, and these qubit probability amplitudes are coupled by local on-site unitary collisional operators (square root of swap gates) and this entanglement is then spread throughout the lattice by unitary streaming operators. As these algorithms place little memory demands, very large grids can be analyzed using only tens of thousands of processors on classical supercomputer architectures.

We discuss spectral properties of both 2D and 3D quantum turbulence and discuss its correlation to 2D and 3D classical Navier-Stokes turbulence. In quantum turbulence, densiy-weighted enstrophy is no longer an invariant and hence there is nothing to force energy to be cascaded to large scales. We report on energy cascades for both 2D and 3D quantum turbulence and discuss their inter-relationship to classical turbulence.

8400-14, Session 3

New type of qubits using incoherent thermal fields

H. Chen, T. Peng, Y. Shih, Univ. of Maryland, Baltimore County (United States)

Since there are still issues in preparing a large number of entangled states, we pay a new way to build qubits by suing incoherent thermal fields. N independent thermal sources are prepared, and each source consists of two orthogonally polarized and mutual incoherent thermal fields. Therefore, a N-photon qubit can be a superposition of the 2^N polarization states,

begin{equation}

|Psi rangle={1over sqrt{2^N}}[|0rangle_1|0rangle_2...|0rangle_{N-1}|0rangle_N+

|0rangle_1|0rangle_2...|0rangle_{N-1}|1rangle_N+...+|0rangle_1|0rangle_2...|1rangle_{N-1}|1rangle_N

+|1rangle_1|1rangle_2...|1rangle_{N-1}|1rangle_N],

end{equation}

where 0 and 1 represent two orthogonal polarizations.

We implemented a N-fold joint-detection with a Franson-type interferometer. A Franson-type interference were observed. The visibility of the interference is more than 71%, after we adopted post subtraction. The experiment demonstrates a simple quantum process of a thermal-qubit. The discovery offers us a prospect for the realization of a large number N-qubits with N incoherent thermal fields for quantum computing purpose.

8400-15, Session 3

Quantum modes of a spin 1/2 particle in a magnetic waveguide

W. M. Golding, U.S. Army Research Lab. (United States)

On atom chips, coherent atomic waveguides made from the magnetic fields near current carrying conductors are important components needed for the construction of certain types of matter wave interferometers that use cold magnetic atoms. The Hamiltonian for the atom guide is symmetric under time inversion, if the reversal of the external magnetic fields is explicitly included in the reversal process. Results that make explicit use of the time reversal symmetry of a magnetic waveguide system to simplify the solution of the quantum behavior of a spin one-half guided particle are presented here. The Frobenius power series method is used to derive a pair of power series solutions that are well behaved at the coordinate origin and an additional pair of solutions that are logarithmic or worse at the origin. All of these solutions are related to one another by the time reversal symmetry of the system. The logarithmic solutions are only useful in coaxial modes when the origin is excluded from the problem. This complete set of series solutions forms the general solution to the atomic waveguide problem. In addition, these series solutions can be numerically summed for a large range of radial distances using arbitrary precision arithmetic techniques so that the behavior of guided modes can be studied numerically.
The series are used to calculate modes, transverse eigenvalues, and magnetic sensitivities for open and closed boundary conditions in both coaxial and non-coaxial geometries.

8400-16, Session 4

Progress in fault tolerance quantum computing

G. N. Gilbert, Y. S. Weinstein, The MITRE Corp. (United States)

We explore the explicit construction of Shor states in quantum error correction. We carry out detailed analyses of the effects of errors, paying special attention to the general case of non-equiprobable errors, i.e., the important and realistic situation in which the probabilities for sigma_x, sigma_y and sigma_z errors are not necessarily the same (sigma_x, sigma_y and sigma_z are the Pauli operators). We obtain exact analytical results for the case of a sufficiently small number of ancilla measurements, and obtain leading order terms for the general case. We calculate and analyze the density operators associated to the Shor states we construct.

8400-17, Session 4

Finsler metrics in quantum circuit optimization

H. E. Brandt, U.S. Army Research Lab. (United States)

In the Riemannian geometry of quantum computation, a Riemannian metric has been exploited for the purpose of quantum circuit optimization [1-4]. Finsler metrics are a more general class of metrics of which Riemannian metrics are a special case based on a quadratic form. A Finsler metric need not be quadratic. In fact Bernard Riemann was the first to consider a metric based on a quartic form, but he settled on a quadratic form because of its greater simplicity. Much later, Paul Finsler introduced Finsler geometry in his thesis. The purpose of the present work is to investigate the suitability of possible Finsler metrics for quantum circuit optimization.

[1] Michael Nielsen and Mark Dowling, “The Geometry of Quantum Computation,” Quantum Inf. Coumput. Volume 8, 0861-0899 (2008).

[2] Howard E. Brandt, “Quantum Computational Curvature and Jacobi Fields,” Contemporary Mathematics, Volume 536, pp. 49-74 (2011).

[3] Howard E. Brandt, “Riemannian Geometry of Quantum Computation,” Proceedings of Symposia in Applied Mathematics, Volume 68, pp. 61-101 (2010).

[4] Howard E. Brandt, “Geodesic Derivative in Quantum Circuit Complexity Analysis,” J. of Modern Optics, Vol. 57, No. 19, pp. 1972-1978, 10 Nov 2010.

8400-18, Session 4

Quantum computing and nonconvex optimization

V. A. Yatsenko III, Institute of Space Research (Ukraine)

In this presentation, we will provide an overview of the research progress in quantum optimization. The focus will be on important contributions during the last years, and will provide a perspective for future research opportunities. The overview will cover the areas of (a) quantum nonconvex optimization, (b) quantum search, (c) twice continuously differentiable constrained nonlinear optimization, (d) mixed-integer nonlinear optimization, and (e) optimization with differential-algebraic models. This report deals with the progress made in applications of quantum computing in control. It concentrates on applying the geometric technique in order to investigate a finite control problem of a two-level quantum system, resonance control of a three-level system, simulation of bilinear quantum control systems, and optimal control using the Bellman principle. We show that a quantum object described by a Schredinger equation can be controlled in an optimal way by electromagnetic modes. We also demonstrate an application of these techniques and an algebra-geometric approach to the study of dynamic processes in nonlinear systems. The information processing by means of controlled quantum lattices is discussed: we present new mathematical models of classical (CL) and quantum-mechanical lattices (QML) and their application to information processing. system-theoretical results on the observability, controllability and minimal realizability theorems are formulated for CL. The cellular dynamaton (CD) based on quantum oscillators is presented. Cellular's quantum computational search procedure can provide the basis for implementing adaptive global optimization algorithms. A brief overview of the procedure is given and a framework called lattice adaptive search is set up.

8400-19, Session 4

Study of improved semantics on elements in quantum computation

N. Wu, F. Song, Nanjing Univ. (China); X. Li, New York City College of Technology (United States)

This paper studies the improved semantics of basic elements in quantum computation, from the perspective of the architecture of quantum computer and quantum programming language. We focus on the improved categorical quantum mechanics (CQM) and study new quantum protocols based on CQM, such as the gate teleportation and super parallelism, etc.

8400-21, Session 4

Generalized Donkor model with induced dipole-dipole-forbidden transitions using maple

C. Jaramillo, Univ. EAFIT (Colombia)

The idea of this work was to generalize the Donkor model (Quantum Information and Computation IX, edited by Eric Donkor, Andrew R. Pirich, Howard E. Brandt, Proc. of SPIE Vol. 8057, 80570O © 2011 SPIE CCC code: 0277-786X/11/$18 doi: 10.1117/12.884501) about the application of induced dipole-dipole forbidden transitions to quantum computation. Using computer algebra I was able to reproduce the original Donkor model. Then I applied some modifications to this model and obtained the respective solutions. It is expected that this model has applications for quantum computation.

8400-22, Session 4

All optical XOR, CNOT gates with initial insight for quantum computation using linear optics

O. Shehab, Univ. of Maryland, Baltimore County (United States)

The design for an all optical XOR gate is proposed. The basic idea is to split the input beams and let them cancel or strengthen each other selectively or flip the encoded information based on their polarization properties. The information is encoded in terms of polarization of the beam. Polarization of a light beam is well understood hence the design should be feasible to implement. The truth table of the optical circuit is worked out and compared with the expected truth table. Then it is proven that the design complies with the linear behavior of the XOR function. Later the XOR gate is used as the key component to design an all optical CNOT gate. The truth table for the gate is logically implied. Then, it is discussed how this approach can be used for Linear Optics Quantum Computation (LOQC). It is shown that with a rotation component, the CNOT gate makes up a universal set of quantum gates based on linear optics. This is a novel design. No power supply, additional input beam or ancilla photon is required to operate. It also doesn't require the expensive and complex single photon light source and detector. Only a single wave length coherent light source is required which is already available in the name of the laser.

8400-40, Session 4

A multipixel three-dimensional superconducting nanowire photon detector

A. M. Smith, Air Force Research Lab. (United States)

Here we propose a design for a superconducting nanowire single photon detector that uses a multi-layer architecture that places the electric leads beneath the nanowires. This allows for a very large number of detector elements, which we will call pixels in analogy to a conventional CCD camera, to be placed in close proximity. This leads to significantly better photon number resolution than current single and multi-nanowire meanders, while maintaining similar detection areas and fill factors. We discuss the reset time of the pixels and how the design can be modified to avoid the latching failure seen in extremely short superconducting nanowires. These advantages give a Multi-Layer Superconducting Number-resolving Photon Detector (MLSNPD) significant advantages over the current design paradigm of long superconducting nanowire meanders. Such advantages are desirable in a wide array of photonics applications.

8400-20, Poster Session

Proposed experiment in two qubit linear optical photonic gates for maximal success rates

A. M. Smith, Air Force Research Lab. (United States); D. B. Uskov, Brescia Univ. (United States); M. L. Fanto, Air Force Research Lab. (United States); L. Ying, L. Kaplan, Tulane Univ. (United States)

We will describe theoretical, numerical and experimental aspect of recent work on imperfect Linear Optical Quantum Computing (LOQC) gates in the style of Knill Laflamme and Milburn. We will discuss our theoretical and numerical approach to LOQC in general and imperfect gates in particular. We will then describe a surprisingly simple experiment that is able to perform or experiment as well as test a wide array of other results.

8400-39, Poster Session

Determination of Fermi energy under size quantization with film thickness in non-parabolic n-GaAs compound semiconductor

S. Singha Roy, JIS College of Engineering (India)

The importance of studying is in the field (Fermi-Dirac statistics) of semiconductors science. In this paper, it will be of much more interest, to investigate the Fermi-Dirac distribution function under the condition of carrier degeneracy, since it will help my revise in transport coefficients and electron dynamics in electronic devices made of degenerate semiconductors (n-GaAs as an example).

8400-23, Session 5

Local availability of mathematics and space-time dependent scale factors for number systems: effects on quantum physics

P. Benioff, Argonne National Lab. (United States)

The work is based on two premises: local availability of mathematics to an observer at any space time location, and the scaling of number systems by arbitrary, positive real numbers. Local availability leads to the assignment of mathematical universes, Vx to each point x of space time. Vx contains all the mathematics that observer, Ox, at x, can know. Each

Vx contains many types of mathematical systems. These include the different types of numbers (natural numbers, integers, rationals, and real and complex numbers), Hilbert spaces, algebras, and many others.

Space time dependence of number systems uses the scaling to define representations, in Vx, of real and complex number systems in Vy. The representations are scaled by a factor, r(y,x) relative to the systems in Vx. For y close to x, r(y,x)=exp (A(x).dx). A(x) is a gauge field. For y distant from x, r(y,x) is a path integral from x to y.

Some consequences of the two premises will be examined. Number scaling has no effect on general comparison of numbers obtained as computation or experimental outputs. The effect is limited to mathematical expressions that include space or space time integrals or derivatives. The effect of A on wave packets and canonical momenta in quantum theory, and in gauge theories, will be described.

8400-24, Session 5

Quantum system decomposition for the semi-classical quantum Fourier transform

B. Greco, Clemson Univ. (United States); J. Lenahan, Imagine One Technology & Management, Ltd. (United States); D. Neumann, S. H. Huerth, Space and Naval Warfare Systems Ctr. Atlantic (United States); C. Paribello, J. Medlock, Clemson Univ. (United States); L. A. Overbey, Space and Naval Warfare Systems Ctr. Atlantic (United States)

For classical simulation, the quantum Fourier transform (QFT) requires very large matrix operations. Previous work has shown that the semi-classical quantum Fourier transform (SCQFT) can approximate the QFT using only single-quantum bit (qubit) unitary gates and measurement operators. However, for simulation, the SCQFT requires these individual decomposed qubits of the quantum system as input to the algorithm. We devise a method to find the best separable approximations (BSAs) of quantum systems as input to the SCQFT. In addition, the SCQFT is modified from the form taken in previous literature to accommodate these BSAs. We introduce an application of the approach on classical radio frequency signals represented through a quantum model. The resulting decomposition and SCQFT variant is computed and evaluated for several simulated results, and an example is given using an experimental signal. We find that the signal decomposition to SCQFT methodology achieves good agreement with the simulated QFT.

8400-25, Session 5

Outcome-influenced sequences of choices of wave functions

J. M. Myers, F. H. Madjid, Harvard Univ. (United States)

Quantum mechanics offers a mathematical language of linear operators by which to explain probabilities extracted from experimental evidence. The proof in 2005 of irreducible room for choice among explanations that fit given evidence elevates evidence (as testimony in numerical form) as the basic entity of quantum mechanics. The traditional form of a quantum-mechanical explanation invokes one or another single wave function. Here we introduce explanations which express feedback between choices of wave function made ``at the blackboard" and experimental activity ``on the workbench." Such explanations involve not a single wave function but sequences of wave functions chosen in response to a flow of experimental outcomes, related to but distinct from the decision procedures introduced by Benioff.

We show the application of outcome-influenced sequences of wave functions to the coordination of multi-agent experiments. (By ``agents" we include not only people but also mechanisms such as recording devices, polarization filters, communications equipment and digital computers organized to manage the other mechanisms.) In particular, in multi-agent experiments, 'spacetime' enters as a mathematical concept in the design and operation of devices that generate quantum outcomes. As used in this report 'spacetime' names a mathematical concept, involving a Lorentzian manifold together with a metric tensor field, used as a term in explanations; however, as recently shown the language of evidence can invoke clock readings without requiring the metric tensor that characterizes a particular flat or curved spacetime. For this reason the choice of quantum explanations can be extended to include the choice of spacetime metric.

8400-26, Session 5

Battle of the sexes: an analysis using Yang-Baxter operators as quantum gates

J. M. Lopez, Univ. EAFIT (Colombia)

The Battle of the Sexes game is analyzed from quantum game theory using quantum initial states as possible strategies for two players. Quantum circuits are presented as schemes of development proposing also the use of Yang-Baxter operators as quantum gates in the circuits. This formalism is implemented using a Computer Algebra Software (CAS) due to its complex and long mathematical treatment. Payoff matrices of the players are given as the results for each case shown. A classical analysis is also made in order to compare the outcomes. Biology and finances applications are also proposed.

8400-27, Session 5

Strictly discordant quantum probes of the qubit depolarizing channel

M. R. Frey, Bucknell Univ. (United States); T. J. Yoder, Franklin & Marshall College (United States)

Quantum mutual information, as defined in terms of von Neumann entropy, captures and quantifies, so far as we understand, all correlations, quantum and classical, between components of a bipartite quantum system. Within this information-theoretic framework entanglement is the most distinguished type of quantum correlation, and a rich body of theory and evidence establishes that entanglement is a fungible resource for quantum computation, metrology, communication, and information processing. Bipartite systems can have quantum states with correlations beyond entanglement. Such non-classical states are called discordant in general and strictly discordant when the quantum state is separable. Strict discord is known in a few instances to be a resource for quantum information processing: for the power-of-one-qubit algorithm in mixed state quantum computation, and for a limited type of teleportation. We show that strict discord can increase the amount of information available from probing a quantum channel. We focus in this study on the qubit depolarizing channel, using quantum Fisher information to measure the information available about the channel depolarizing probability. We consider channel probes prepared, along with an ancilla, in a separable two-qubit Bell-diagonal state. The Bell-diagonal states are a three-parameter set of quantum states whose various features, marginal purity, entanglement, classical correlation, and strict discord, admit both analytical expression and geometrical interpretation. We find that, in the absence of entanglement and controlling for marginal purity and degree of classical correlation, any increase in strict discord between the probe and ancilla has an accompanying increase in available information. This work advances the study of quantum channel probes. It also has implications for the broad proposition that strict discord has to some degree a standing comparable to that of entanglement as a fundamental resource for quantum information processing.

8400-28, Session 5

A geometric view of quantum cellular automata

J. R. McDonald, Air Force Research Lab. (United States); H. A. Blair, Syracuse Univ. (United States); P. M. Alsing, Air Force Research Lab. (United States)

Nielsen, et al. proposed a view of quantum computation where determining optimal algorithms is equivalent to extremizing a geodesic length or cost functional. These results are highly suggestive of an action principle on the space of N-qubits interacting via local operations. The cost or action functional is given by the cost of unitary operators acting on local qubits leading to causal dynamics. Here we propose a view of information geometry, and particularly quantum cellular automata, for quantum algorithms where the intrinsic causal structure determines topology and information distance sets the local geometry. This naturally leads to geometric characterization of hypersurfaces in a quantum cellular automaton. While in standard quantum circuit representations, the connections between individual qubits, i.e. the topology, for hypersurfaces will be dynamic, quantum cellular automata have readily identifiable static hypersurface topologies determined via the quantum update rules. In this paper we demonstrate construction of quantum cellular automata geometry and discuss the utility of this approach.

8400-29, Session 6

Quantum knots and their applications

S. J. Lomonaco, Jr., Univ. of Maryland, Baltimore County (United States); L. H. Kauffman, Univ. of Illinois at Chicago (United States)

No abstract available

8400-30, Session 6

Quantum algorithms for the Jones polynomial and Khovanov homology

L. H. Kauffman, Univ. of Illinois at Chicago (United States); S. J. Lomonaco, Jr., Univ. of Maryland, Baltimore County (United States)

This talk will review quantum algorithms for computing the Jones polynomial that use unitary representations of the braid group and a newer algorithm that uses a Hilbert space of states associated to the state expansion of the bracket polynomial. The latter algorithm applies to yield algorithms for the two variable Poincare polynomial associated with Khovanov homology. In this sense we have a quantum algorithm for Khovanov homology. Khovanov homology is a homology theory associated with a knot or link and a specialization of its Poincare polynomial gives the Jones polynomial.The algorithm we have is not efficient, and one purpose of this paper is to explore possibilities for designing faster algorithms for this structure.

8400-31, Session 6

Possible quantum algorithms for the Rasmussen's invariant

J. F. Ospina, Univ. EAFIT (Colombia)

Topological quantum computation is concerned with quantum algorithms for topological invariants for knots, links, graphs and low dimensional manifolds. Examples of such invariants are Jones polynomial, HOMFLY polynomial, Tutte polynomial, Bollobàs-Riordar polynomial, Khovanov homology, Turaev-Viro invariant and the Rasmussen`s invariant. Actually exist quantum algorithms for the previously mentioned invariants except for the Khovanov and Rasmussen invariants. The object of the present work is to study the possibility to desing quantum algorithms for the Rasmussen invariant. The strategy to use consists in the application of the Gauge theory to formulate the Rasmussen invariant and then to traduce the gauge facts in quantum algorithms. Finally some simulations of the obtained algorithms are implemented using computer algebra software.

8400-32, Session 6

Applications of the Yang-Baxter-Rowell equation to topological quantum computation

A. K. Arnedo, Univ. EAFIT (Colombia)

The main goal of this paper is to apply the Yang-Baxter-Rowell equation in topological quantum computation, using the symbolic computational software Maple. Initially, using Maple, I reproduced the Dye classification of the 4x4 unitary solutions of the Yang-Baxter equation. Then, also using Maple, I reproduced the solutions given by Rebecca Chen to the Yang-Baxter-Rowell equation. Finally the obtained solutions were considered as quantum gates and were incorporated in quantum circuit models and quatum games, such as the Grover algorithm and the game Battle of the Sexes.

It is expected that a future investigation can provide a more complete classification of the solution to the Yang-Baxter-Rowell equation and its possible applications on topological quantum computation.

8400-33, Session 7

Nonlocality, entanglement witnesses, and supra-correlations

P. M. Alsing, Air Force Research Lab. (United States); H. A. Blair, Syracuse Univ. (United States)

While entanglement is believed to underlie the power of quantum computation and communication, it is not generally well understood for multi-partite systems. Recently, it has been appreciated that there exists proper no-signaling probability distributions derivable from operators that do not represent valid quantum states. Such systems exhibit supra-correlations that are stronger than allowed by quantum mechanics, but less than the algebraically allowed maximum in CHSH Bell-inequalities (in the bipartite case). These probability distributions are derivable from an entanglement witness W, which is a non-positive Hermetian operator constructed such that its expectation value with a separable quantum state (positive density matrix) rho_sep is non-negative (so that Tr[W rho] 2. We will also examine the failure of this generalization in the tripartite case, and its relation to the lack of a generalization of the pure state Schmidt decomposition for N > 2 parties.

8400-34, Session 7

A multipli-entangled photon source for cluster state generation

M. L. Fanto, R. K. Erdmann, P. M. Alsing, C. J. Peters, Air Force Research Lab. (United States)

This paper expands prior work on an entangled photon source (Schioedtei), generating six pairs of photons via spontaneous parametric down-conversion in a single pass configuration. Experimental results at 810nm of the second generation of this crystal assembly are discussed and other wavelength regimes will be considered. The design and fabrication considerations for a group velocity matched superlattice version are included. An application of this source enables particular multi-qubit cluster states to be generated in a compact unidirectional configuration. This configuration simplifies the interferometric stability for

any associated feed-forward methods required in photon-based quantum logic circuitry.

8400-35, Session 7

Simulation of Bell states with incoherent thermal light

T. Peng, Univ. of Maryland, Baltimore County (United States)

This paper reports our experimental study of thermal light multi-photon qubits. Taking advantage of two-photon interference, we have successfully observed Bell-type correlation from mutually incoherent and orthogonal polarized thermal fields. The visibilities of the polarization correlation and the temporal anti-correlation both exceed 71%, indicating the behavior of a two-photon Bell state or a two-digit qubit. In the simulation of the behavior of a two-photon qubit,we have (i) prepared a pair of orthogonal wavepackets A and B; (ii) prepared two different yet indistinguishable alternative ways for a pair of wavepackets A and B to produce a joint photodetection event; (iii) achieved an experimental condition in which the statistical ensemble average does not average out the interference of each random photon pair while taking into account all possible realizations of the fields from one joint photodetection event to another. Our success in simulating a two-photon qubit is a great step and has brought us closer to the capability of simulating the behavior of n-photon qubits for computation purposes. At least, this experiment should be helpful in constructing n-photon qubits from incoherent thermal radiation.

8400-36, Session 7

Generation, detection, and applications of quantum hyper-entangled and entangled states

J. F. Smith III, U.S. Naval Research Lab. (United States)

Methods of generating N00N, M&N, linear combinations of M&N states as well as more complicated quantum entangled and quantum hyper-entangled states will be considered. Quantum hyper-entanglement refers to quantum entanglement in more than one degree of freedom, e.g. energy-time, polarization, orbital angular momentum, etc. Internal noise and loss within the entanglement or hyper-entanglement generators and external noise and loss due to atmospheric effects, detectors and targets are modeled. Mathematical and computational analysis related to the devices that generate these entangled or hyper-entangled states will be provided. The following will be derived: closed form expressions for wave function normalization, wave function, density operator, reduced density operator, visibility, phase error, bearing error, the symmetrized logarithmic derivative, the quantum Fisher information, the quantum Cramer-Rao lower bound, the relevant projection operators and the related probability of detection expressions. Various schemes for generation and detection of the entangled or hyper-entangled states will be considered. The entanglement generators will be given in terms of linear and nonlinear optical devices. Entanglement and hyper-entanglement at non-optical frequencies will be discussed. Optimization criteria for the quantum states, generation and detection schemes and designs optimal with respect to the criteria will be discussed. Applications of the generated states to sensors for producing super sensitivity and super resolutions will be analyzed. The fundamental role of post-selection and coincidence measurement for generating entanglement is included. A method using these approaches for quantum imaging is provided that gives N times classical resolution, where N is a quantum number associated with the system, e.g. the number of photons.

8400-37, Session 7

Nonlocal realism considered for entangled photon phenomena

R. K. Erdmann, P. M. Alsing, R. J. Michalak, M. L. Fanto, C. J. Peters, Air Force Research Lab. (United States)

The quantum mechanical (QM) description of entangled phenomena has been in conceptual conflict with local realism since its origin. In response to the related issues raised by the Einstein-Podolsky-Rosen paper, John Bell subsequently sharpened the conflict's focus by inspiring the extensive experimental work, that supported QM. However, it did not rule that real properties, for individual systems, could be sustained in a proper description of nature if they were of a non-local nature. The QM description is itself non-local and provides a correct description of the observed phenomena, entangled photons in particular. Whether a 'non-local real' model can provide this, or whether any plausible ones are ruled out in principle or by experiment, is examined. Representative proposed models and appropriate modifications to those as well as related experiments are discussed. Fundamentally more speculative approaches that could sustain both locality and realism in Many Worlds type interpretation are briefly assessed with a view to whether experimental distinction may prove possible. Overall the critical examination of these models, even without plausible if they do not necessarily yield fully satisfactory alternate descriptions to that of QM, provides additional insight to picturing how the QM description works. It is concluded that at a fundamental level information entailed in individual system properties necessarily precludes that in the joint (entangled) properties of photons and vice-versa.

8400-38, Session 7

Generating and storing nonclassical correlations in a warm Rb vapor cell with buffer gas

M. Bashkansky, F. K. Fatemi, I. Vurgaftman, U.S. Naval Research Lab. (United States)

Stored non-classical correlations are needed to realize quantum memory (QM) in long-distance quantum communications. The use of warm atomic-vapor cells in the DLCZ (Duan, Lukin, Cirac, and Zoller) protocol is appealing because of the relatively low experimental complexity. Unfortunately, a review of the published literature finds multiple inconsistencies and ambiguities in the experimental conditions and geometry. Quantum correlations in the single-photon regime and using a single atomic cell have not been reported previously to the best of our knowledge (the only published claim satisfying these requirements was later retracted). Our work demonstrates that this is possible with the proper filtering and detuning even in the presence of collisional fluorescence in the cell with a buffer gas. Copropagating write and read beams are used, and it is shown that the counterpropagating geometry is useful only for compact cold atomic traps. Non-classical correlations, measured as the cross-correlation between the emitted Stokes and anti-Stokes photons above the maximum classical value of 2, last for approximately 4 microseconds. The collisional fluorescence during the read process is found to be uncorrelated with anti-Stokes photons and can be removed by spectral filtering without affecting the fidelity of QM. The remaining noise is likely due to the four-wave mixing mechanism and can be potentially controlled with the use of circularly polarized photons. To the best of our knowledge, this is the first demonstration of stored non-classical correlations based on the original DLCZ protocol in warm atomic vapor with a buffer gas.

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8401-01, Session 1

MRA-based wavelet frame and applications

Z. Shen, National Univ. of Singapore (Singapore)

One of the major driving forces in the area of applied and computational harmonic analysis during the last two decades is the development and the analysis of redundant systems that produce sparse approximations for classes of functions of interest. Such redundant systems include wavelet frames, ridgelets, curvelets and shearlets, to name a few. This talk focuses on tight wavelet frames that are derived from multiresolution analysis and their applications in imaging. The pillar of this theory is the unitary extension principle and its various generalizations, hence we will first give a brief survey on the development of extension principles. The extension principles allow for systematic constructions of wavelet frames that can be tailored to, and effectively used in, various problems in imaging science. We will discuss some of these applications of wavelet frames. The discussion will include frame-based image analysis and restorations, image inpainting, image denosing, image deblurring and blind deblurring, image decomposition, segmentation and CT image reconstruction.

8401-02, Session 2

Interdisciplinary educational approach to the human sciences

Y. Zheng, Alcorn State Univ. (United States); N. Zhang, Univ. of the District of Columbia (United States); H. Szu, Catholic Univ. of America (United States)

This paper briefly describes the short history of our conferences over the past 15 years. The first conference was called “Wavelet Applications,” part of the SPIE OE/Aerospace Sensing Symposium held at Orlando in 1994. Now the conference is referred to as “Independent Component Analyses, Compressive Sampling, Wavelets, Neural Net, Biosystems, and Nanoengineering,” part of the SPIE Defense, Security, and Sensing, which will be held at Baltimore in 2012. The “compressive sampling” is a newly added topic for the 2012 conference. The mission of this conference is to provide an interdisciplinary educational forum for the worldwide optical engineers to share their experience and to exchange their ideas. Thus, the best researchers are invited to speak in the conference and to contribute to the proceeding every year. To honor the outstanding researchers, a pioneer award plaque is presented to each winning speaker. Then the current recipients choose the winners for next year from their peer researchers, and so on so forth. This mechanism seems to be working very well so far, as long as the conference organizers stay out of the selection process. The conference topics are organized as the organic functions of the human body. Wavelets application to adaptive wavelets are like human ears and eyes; ICA to unsupervised learning resemble some functions of a brain; and nanoengineering and biomedical wellness to systems biology is somewhat like the human body. The new topics in information processing and compressive sampling is to clean the imminent digital pollution (due to huge amounts of redundant data) in our society. All aforementioned topics are organically combined into our conference, which can function as robust and efficient as the human body system. In this paper, we shall list all pioneer recipients, their papers, web sites, and a few lines of their highlights.

8401-03, Session 2

Semi-supervised learning of heterogeneous data in remote sensing imagery

J. J. Benedetto, W. Czaja, J. Dobrosotskaya, T. Doster, K. Duke, Univ. of Maryland, College Park (United States); D. B. Gillis, U.S. Naval Research Lab. (United States)

We introduced Schroedinger Eigenmaps - a new semi-supervised manifold learning and recovery technique. This method is based on an implementation of graph Schroedinger operators with appropriately constructed barrier potentials as carriers of expert/labeled information. In this paper, we analyze the features of Schroedinger Eigenmaps built for fused heterogeneous data. The imaging modalities which we shall incorporate in our analysis include multispectral and hyperspectra imagery, bathymetry data, and spatial information. These techniques are combined into the optimal embedding of the input data into a joint graph representation. For the purpose of constructing efficient methods for building the potential barriers we refer to expert knowledge and ground-truth data, as well as to using automated demixing techniques such as, e.g., ORASIS. We also investigate the role of different sources of the barrier potential locations, which may come restricted to individual modalities, as well as selecting the barrier potentials across all the different sources of data.

8401-04, Session 2

A wavelet-based method for multispectral face recognition

Y. Zheng, Alcorn State Univ. (United States)

A wavelet-based method is proposed for multispectral face recognition in this paper. Gabor wavelet transform is a common tool for orientation analysis of a 2D image; whereas Hamming distance is an efficient distance measurement for multiclass classifications such as face identification. Specifically, at each frequency band, an index number representing the strongest orientational response is selected, and then encoded in binary format to favor the Hamming distance calculation. Multiple-frequency orientation codes are then organized into a face pattern byte (FPB) by using order statistics. With the FPB, Hamming distances are calculated and compared to achieve face identification.

A face recognition method is usually originated from one specific band of images. For example, the FPB method was initially created using thermal (LWIR) images, while the EBGM method was originated with visible (RGB) images. When two or more spectral images from the same subject are available, the identification accuracy and reliability can be enhanced using information fusion. Mean fusion and neural network are examples of score level fusions. We will compare the identification performance of applying variant recognition methods to multispectral face images, and explore the fusion performance of combing the multiple scores from several methods and multispectral face images.

8401-05, Session 3

Face recognition from a moving platform via sparse representation using compressive sampling

M. Hsu, The George Washington Univ. (United States); C. C. Hsu,

S. Mandelson, Trident Systems Inc. (United States); H. H. Szu, The Catholic Univ. of America (United States)

In this paper, we explore asymmetric interactions among multiple neighborhoods in various data sets. Considering a generalized graph G= (υ _i,ε_ij,W_(i,j)), where the measure over the edge set ε_ij is directional, W_(i,j)≠W_(j,i), I prove that the connectivity amongst groups is represented by the ground state eigenvalue, as in the case of the symmetric weight matrix, where the rowless "Graph-Laplacian" is defined by [L]≡[[δ_(i,j) d_i]-[W_(i,j)]] and the directional centrality d_i≡∑_(j=1)^N W_(i,j) has N intersecting lines at multiple points in O ' R^N. Further, I show the geometric meaning of recursive embedding.

8401-06, Session 3

Sub-pixel registration of moving objects in visible and thermal imagery with the factored 3-way restricted Boltzmann machine

S. M. Won, S. S. Young, U.S. Army Research Lab. (United States)

Motion estimation is critical in object tracking and image super-resolution. Traditionally, motion estimation is done by optical flow or correlation method. However, motion estimation for moving objects does not depend only on shift estimation, but also involves object classification between the object of interest and the background. In this paper, we present the use of factored 3-way restricted Boltzmann machines to estimate a moving object's translational shift in an image sequence. The factored 3-way restricted Boltzmann machine is a machine learning algorithm used to infer the spatial transformation that occurs between two images while distinguishing moving objects from the background. The accuracy of the image registration will be tested at the gross and sub-pixel level. Gross shift estimation accuracy is assessed by comparing estimated shifts against a ground truth. Sub-pixel shift estimation accuracy is assessed by synthetically downsampled images. Evaluations show that the factored 3-way restricted Boltzmann machine gives accurate gross shift estimation results even in noisy imagery where "classical" methods yield inaccurate results. The improvement of gross and sub-pixel registration is demonstrated using visible and thermal imagery.

8401-07, Session 3

PCA/LDA approach for text-independent speaker recognition

Z. Ge, S. R. Sharma, M. Smith, Purdue Univ. (United States)

This paper presents a novel PCA/LDA-based approach for text independent speaker recognition using Mel-Frequency Cepstral Coefficients (MFCCs). It provides fast training and real-time recognition, while maintains competitive performance to statistical model-based systems. This algorithm may be desired useful in the case like conferencing applications, where the number of speakers is limited and the processing time needs to be very short.

This approach first extracts key frames using K-means clustering. Then, for each speaker, two eigenspaces based on Principle Component Analysis (PCA) and Linear Discriminant Analysis (LDA) are computed. To classify a testing speaker, the ratios of the original-to-projection difference over the projection to PCA and LDA eigenspaces of each speaker are measured respectively using Euclidean metric. The weighted sum of these two ratios is then computed as the PCA/LDA classifier. Using LDA compensates the PCA limitation which is feature components with large variance may not necessarily be discriminative for speaker recognition.

A subset of the TIMIT corpus is used with 100 speakers and 10 utterances each. 6 and 2 utterances are used for system enrollment and validation, the rest 2 are used for testing. Several parameters are investigated, like a) the dimensions of PCA and LDA with corresponding recognition performance and computational time and b) weights on each method. Best results show 97% and 92% accuracy in 30 and 50 speaker scales with slightly larger weight on PCA, using MFCCs with delta and double delta features. These are comparable to the conventional MFCC-GMM framework, but with significantly less time to train and operate.

8401-09, Session 4

Advances in audio source seperation and multisource audio content retrieval

E. Vincent, IRISA / INRIA Rennes (France)

Audio source separation aims to extract the signals of individual sound sources from a given recording. Recently, several advances have been made, which improve the robustness of source separation in real-world challenging scenarios and enable its use for multisource content retrieval tasks, such as automatic speech recognition (ASR) or acoustic event detection (AED) in noisy environments.First, I will introduce a general probabilistic framework for audio source separation and discuss its advantages compared to earlier approaches such as independent component analysis (ICA) and sparse component analysis (SCA). I will explain how cues as diverse as harmonicity, spectral envelope, temporal fine structure or spatial location can be jointly exploited and play a few sound examples. Second, I will present the uncertainty decoding framework for the integration of audio source separation and audio content retrieval. I will show how the uncertainty about the separated source signals can be estimated, propagated to the features and exploited by a classifier. I will illustrate the results for speaker recognition in a real-world noisy domestic environment. I will conclude by listing some remaining challenges in these fields.

8401-10, Session 5

Blind signal separation and extraction based on permutation-free frequency-domain ICA

C. Choi, W. Chang, S. Lee, KAIST (Korea, Republic of)

Several new approaches are reported for blind signal separation (BSS) and blind signal extraction (BSE) based on frequency-domain independent component analysis (ICA). The permutation problem and/or scaling indeterminacy of frequency-domain ICA have been removed by incorporating dependency among frequency components, i.e., pitch-based frequency structures or multi-resolution spectrogram. The resulting BSS algorithm demonstrated much better signal separation performance, while the resulting BSE demonstrated real-time operation with much less computing resources and only slight performance degradation from that of BSS.

8401-11, Session 5

Discriminant feature extraction by combining unsupervised and supervised learning

C. Kim, B. Kim, C. Lee, H. Song, S. Lee, KAIST (Korea, Republic of)

Discriminant feature extraction algorithms, i.e., dICA (discriminant Independent Component Analysis) and dNMF (discriminant Non-negative Matrix Factorization), are applied to speech, speaker, and music recognition tasks as well as text mining tasks. In addition to the independence and representation capability the discriminant feature extraction algorithms maximize Fisher's linear discriminant or its variant for better recognition performance. Applications of these feature extractors to spectrogram resulted in much better features for speech, speaker, and music recognition. Both single and multi-frame approaches are reported. Also, better performance is reported for text mining from word-frequency matrices.

8401-12, Session 6

The effects of speckle noise removal on LDV vital-sign measurement accuracy

K. A. Byrd, H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

LDV is a sensing technology used to acquire non-contact surface vibration signatures of objects at both close range and standoff distances. LDV sensors detect Doppler shifts in the frequency of laser light reflected from vibrating (moving) objects. One advantage (and disadvantage) to LDV is its ability to detect highly sensitive (small) vibrations, i.e., sub-micrometer per second vibration velocities. Assuming that measurements are not taken from within a vacuum, signal fidelity is always a concern due to distortion from unknown sources of clutter and noise. Distortions such as environmental clutter, sensor noise (speckle dropouts) and accidental movements/motions by the target introduce unwanted peaks in Fourier spectra, and as a result, must be addressed (separated or filtered out) in order to make accurate vital sign measurements from the true signal of interest. In this paper, we evaluate the performance of two speckle noise removal algorithms used to post-process vital sign signatures made with an LDV, the kurtosis ratio (KR) and Fast Independent Component Analysis (Fast-ICA).

8401-13, Session 6

Augmented reality for recognition of human intention

J. C. Jenkins, H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Our soldiers face a growing set of battlefields and adversaries who don't wear uniforms. We still must train our soldiers to be vigilant despite this ambiguity. We wish to develop a training module which integrates various human intentions into cultural awareness scenarios. Scenarios have been generated by interviewing returning Veterans, injured Warriors, and/or active Soldiers who have experienced unique situations on the battlefield that conventional training did not address, or cannot represent realistically enough by current training material. Using these scenarios, we can generate a modulus to test 'see no see,' [2] e.g. how hostile intention is masked by environmental and culture variability in all sensor modalities for still and moving imagery. We have been using Augmented Reality (AR: all parts are real including their interaction but the whole scenario is fabricated) techniques common to Hollywood/Video Game professionals[1]. We started by creating 3 libraries of 3D models: F- Foreground targets, B - Backgrounds (scenery, clutter, etc.), I_C - Culture Interactions (between F & B). We illustrate how to generate realistic, high-definition 3D embodiments of real targets in a desired spectrum, position various Foregrounds and Backgrounds and select the I_C with a touch screen interface, then automatically fuse F+B+I_C together into scenarios. Varying F, B, or I_C is done easily by a tool set once the objects of interest, F, B, I_C have been created in a 3D mesh format and able to be viewed from any perspective in a 3D viewing environment and perhaps streamed from a mobile device as well.

8401-15, Session 6

Robust binocular disparity system based on Nios II processor

D. Gonzalez, G. Botella Juan, Univ. Complutense de Madrid (Spain); U. Meyer Baese, A. D. Meyer Baese, The Florida State Univ. (United States)

Embedded systems are used extensively due the many applications in aerospace, robotics, vehicles, industry, medicine and so on. One of the relevant topics regarding to machine vision in the applications described, is the binocular disparity, very useful for navigation and tridimensional object recognition. We present an embedded system which estimates the stereo matching disparity. This architecture is also tolerant again faults due the hybrid hardware redundancy of the final scheme. This fully custom system is built under SoPC platform from Altera, based on Nios II processor. Performance, accuracy and resource usage of the final system are presented.

8401-16, Session 7

Compressive signal processing

R. G. Baraniuk, Rice Univ. (United States)

Sensing and imaging systems are under increasing pressure to accommodate ever larger and higher-dimensional data sets; ever faster capture, sampling, and processing rates; ever lower power consumption; communication over ever more difficult channels; and radically new sensing modalities. The foundation of today's digital data acquisition and processing systems is the Shannon/Nyquist sampling theorem, which asserts that to avoid losing information when digitizing a signal or image, one must sample at least two times faster than the signal's bandwidth, at the so-called Nyquist rate. Unfortunately, the physical limitations of current sensing systems combined with inherently high Nyquist rates impose a performance brick wall to a large class of important and emerging applications. This talk will overview the foundations and recent progress on compressive signal processing, a new approach to data acquisition and processing in which analog signals are digitized not via uniform sampling but via measurements using more general, even random, test functions. In stark contrast with conventional wisdom, the new theory asserts that one can combine "sub-Nyquist-rate sampling" with digital computational power for efficient and accurate signal acquisition when the signal has a sparse structure. The implications of compressive sensing are promising for many applications and enable the design of new kinds of communication systems, cameras, microscopes, and pattern recognition systems. Special emphasis will be placed on the pros and cons of the compressive sensing technique.

8401-17, Session 8

Adaptive compressive sampling learned by ANN

S. Lee, KAIST (Korea, Republic of); H. Szu, Catholic Univ. of America (United States)

We introduce the unsupervised learning artificial neural network methodology to enhance the performance of CS & CSp.

8401-18, Session 8

Video image cliff notes

H. H. Szu, The Catholic Univ. of America (United States); C. C. Hsu, Trident Systems Inc. (United States)

Technically, our ANN approach always senses all in full resolution; but rejects redundant frames (not pixels), keeps only distinctive different representations. Therefore, we have by-passed the need to develop a rapid and robust image recovery for real-time video. Our approach strives to be information-compressive sampling (CSp) like an automatic cliff notes with the goal of reducing the cost of a human analyst overcoming data pollution in the digital age.

8401-19, Session 8

Elucidating compressive sensing from Nyquist critical sampling viewpoint

C. C. Nguyen, H. H. Szu, The Catholic Univ. of America (United

States); K. C. Reinhardt, Air Force Office of Scientific Research (United States)

In one dimension time series, we can easily understand that a simple cosine wave that requires two discrete measurements to interpolate an smooth curve. In the continuation of the cosine curve may require only one discrete measurement, since the first segment of cosine has already determined the up-down entrance trend if there is no singularity jump in between two segments. Thus, 2 per modes are over-killed if two oscillations have the (smooth) coupling. Such a mode-mode coupling creates a macro-mode called information degree of freedom. We suggest either the locality or the coupling might permit the modification of Nyquist critical sampling as 2 discrete measurements per every independent degree of freedom.

More generally speaking, we know from our experience in adaptive Wavelet Transform, we can adaptively or iteratively concentrate the spatial frequency information content so that some spatial frequency becomes negligibly small in the limiting sense. Especially, in a radiation imaging, the imaging formation medium has usually a mode-mode coupling that is no longer making each Fourier mode independent. Therefore, the information degrees of freedom are less than the Fourier modes, that sparseness form the basis of CRT&D CS image recovery.

8401-20, Session 8

EOIR compressive sensing camera design

A. Ramirez, G. R. Arce, Univ. of Delaware (United States)

We will describe a design about a spectral imaging camera that can cover from the visible wavelength to 2 micron SWIR.

8401-21, Session 9

Design of baseball hats with compressive sensing electrodes for wireless EEG brainwaves

H. Szu, Catholic Univ. of America (United States); T. Jung, Univ. of California, San Diego (United States); T. Yamakawa, Kyushu Institute of Technology (Japan)

The week-long procedure of removing a part of epileptic patient brain surgically has been successfully reduced to a day-patient procedure. This was possible because Yamakawa of KIT applied an ICA algorithm identifying the brain epileptic center, and burned it off with a fibrotic laser [1]. Recently, UCSD has produced a wireless EEG head-mount in the shape of a convenient motorcycle hamlet [2], and demonstrated an ICA algorithm can de-artifacts, de-noise, and find the blind sources. UCSD can further solve the intrinsic unknown mixing matrix to assign the sources to known location of measurement electrodes.

To achieve a better localization of epileptic center, we wish to apply the convenient UCSD hamlet. For the proof of concept, given the current electrodes arrangement and data, we explore virtually the Condes, Romberg, Tao, & Donohoe (CRTD) Compressive Sensing (CS) methodology to design under-sampled electrodes of a UCSD EEG head-mount device. Given a region among N= nxn pixels/electrodes, we explore a refined CS methodology, according to an organized sparseness array, rather than CRT&D purely random sampling, to achieve the same requirement of M linear independent combinations, M<<N. Consequently, the recovery of original N measurements from M measurements becomes faster within 300 microsecond interval to track the real-time brainwave migration dynamics.

Furthermore, Szu's Lagrange Constraint Neural Network (LCNN) algorithm derived at the Brain thermodynamic equilibrium at the isothermal temperature (37oC) requires the minimum of Helmholtz free energy, a minimum internal energy and maximum a-priori sources entropy. The result is similar, but different to the Bell-Sejnowski-Amari-Oja (BASO) filter concept requiring an averaging of 102 pixels/electrodes data for the statistical stability.

To improve the hardware, we might increase the surface skin-contact area by tenfold, if each electrode is built with gecko foot like, together with elastic dry rod conforming to a head shape reducing the contact impedance by 2 folds.

8401-22, Session 9

Biomedical wellness applications by Smartphones

H. H. Szu, The Catholic Univ. of America (United States); C. C. Hsu, Trident Systems Inc. (United States); J. S. Landa, BriarTek, Inc. (United States)

The imaged person must be estimated from day-night video image processing. In case of in-door, a smartphone computes from IMU without GPS reception. In case of outdoor, a smartphone has received within line of sight 5 GPS satellites transmitting data on two frequencies, L1 (1575.42 Mhz) and L2 (1227.60 MHz) disciplined by the atomic clocks aboard the satellite. The measured travel times of these satellite L-band signals to the smartphone transceiver are used to compute the ranges. Every Smartphone has 3 build-in radios (cellular, Blue Tooth, and Wi Fi0, and GPS as well as IMU. The difference is the antenna sensitivity and the precision of IMU based on a proving mass on a MEMS or a miniaturized 3-axial laser gyroscope, and the time integration in hardwired electronic integrators.

The Center of Disease Control (CDC) reported heat-related illnesses are the No. 1 weather-related killer, accounting for about 700 deaths a year by Heat Stroke(HS). HS begins with the sensation of cramps, dizziness, headaches, nausea and thirst. His or her skin becomes red, hot, dry, and body temperature rises above 103 oF and can no longer cool itself. Since potential HS may suffer temporarily mental delusion, imbalance, or may impair the self-awareness, normal sensitivity and common sense in a continued dehydration state, smartphone day & night cameras may help. We can address how to mitigate the environmental variability for standoff measurement of under 3H (hazy, hot, and humid) weather conditions, emergency help is essential because the body's temperature can quickly escape to 106 degree Fahrenheit (oF) and damage organs or lead to death. The scientific reliability of the smart-phone dual camera system may rely on having both the day and the night cameras. We shall follow standard FDA double-blind with control protocol for test the FDA category C device.

8401-23, Session 9

Compressive sampling approach to visual attention in image scene analysis

C. H. Chu, M. A. Pratt, A. Singh, Univ. of Louisiana at Lafayette (United States)

Many image scene analysis applications require a computational approach to visual attention. Examples are the detection of objects from a background in surveillance or the detection of road signs in video collected by a vehicle. The foreground in these applications is typically sparse in spatial support. Compressive sampling enables an approach to reconstruct the sparse map of image regions that stand out from the background using fewer measurements. We present results that use a convex optimization algorithm for recovering the sparse map in the wavelet domain. Besides being sparse in the transform domain, the background of natural images has an interesting property that the amplitude of the averaged Fourier spectrum is approximately proportional to the inverse of the frequency. This further allows us to approximate an average background signal for extracting the out-of-ordinary foreground signal corresponding to objects of interest. We present experimental results to illustrate different approaches to extracting the foreground signals.

8401-24, Session 9

Compressive sampling for self-reference rejection of astronomical atmospheric distortion

K. J. Jones, WBAO Consultant Group (United States)

Compressive Sensing is based on purely random sparse masks. There is additional benefit in using image changes to make retrievable graphical indices. Organized sparseness has been coined as Compressive Sampling: sensing but skipping redundancy without altering the original image, i.e. space-time changes. Image degradation is imaging through inhomogeneous media. A time selection technique is employed to correct image degradation using multiple frame image sequences. Selective rejection and piecewise assembly extracts the needed information using self-referencing to reorganize the high-spatial-frequency content. Adaptive Optics operates at a time scale of 1 ms and aims to compensate atmospheric phase fluctuations across the telescope aperture to achieve diffraction limited resolution. A wavefront distorted by the atmosphere is reflected from a deformable mirror by hundreds of actuators. It operates in closed-loop measuring the residual wavefront error using a wavefront sensor. Corrections are applied to update the wavefront 1000 times per second to match the rapidly changing atmospheric turbulence. Self-referencing is already built into the system. Compressive Sampling will be applied to the incoming photons produced by Laser Guide Star excitation of the Na mesospheric layer. The latter is temporally and spacially highly variable. Compressive Sampling will be applied to reduce redundancy, enhanced WaveFront Correction and reduce the number of correction updates.

8401-25, Session 9

Avoiding the inverse fractal problem for compressive sampling of 1/f data sets

H. M. Jaenisch, Licht Strahl Engineering, Inc. (United States)

We present a novel fractal Iterated Function System (IFS based) data interpolation algorithm enabling compressive sampling of 1/f data sets. We avoid the classical inverse IFS parameter estimation problem by using a novel analytical function driven variant of the random Iterated Function System (IFS) algorithm. We attempt to optimize the parameters of the analytical driver equation to optimize the data reconstruction by minimizing errors using various state-of-the-art genetic algorithms. We demonstrate our encouraging results and detail our methods and findings.

8401-26, Session 10

Toward practical SERS sensing

Y. Zhao, The Univ. of Georgia (United States)

Since its discovery more than 30 years ago, the surface enhanced Raman scattering (SERS) has been recognized as a high sensitive detection technique for chemical and biological sensing and medical diagnostics. However, the practical application of the remarkable analytical sensitivity of SERS has not been widely accepted as a viable diagnostic technique due to the difficulty in preparing robust and reproducible substrates of the correct surface morphology that provide maximum SERS enhancements. Recently, we demonstrate that the aligned silver nanorod (AgNR) array substrates engineered by the oblique angle deposition method are capable of providing extremely high SERS enhancement factors (>10^8). The substrates are large area, uniform, reproducible, and compatible with general microfabrication process. The enhancement factor depends strongly on the length of the Ag nanorods, the substrate coating, the polarization of the excitation light, as well as the incident angle. With the optimized AgNR SERS substrates, we also show that SERS is able to detect trace amount of virus, bacteria, microRNAs, or other chemical and biological molecules, and distinguish different viruses/bacteria and virus/bacteria strains, suggesting that this technology can be applied to detect genetically modified viruses that may be agents of bioterrorism. The substrate can be tailored into multi-well chip for high throughput screening of chemical/biological specimen, integrated into fiber tip for portable sensing, incorporated into fluid cells or microfluidic devices for in situ real-time monitoring dynamic process, or fabricated onto a flexible substrate for tracking and identification. By combining this unique SERS substrate with handheld Raman system, it can become a more practice sensor system for battle field application and portable device for public safety monitoring and security screening. With the help of independence component analysis and chromatography technique, the AgNR chip can also be used to identify and differentiate components in a mixture. All these development has demonstrated that AgNR SERS substrates could play an important role for practical sensing applications in future defense and security.

8401-27, Session 11

A NANO enhance to Moore’s Law

J. Wu, Y. Shen, The George Washington Univ. (United States); K. C. Reinhardt, Air Force Office of Scientific Research (United States); H. Szu, The Catholic Univ. of America (United States)

In past 46 years, Intel Moore observed an exponential doubling in the number of transistors in every 18 months through the size reduction of individual transistor components since 1965. In this paper, we explore the nanotechnology impact upon the Law. To begin with a trivial consideration at a normal energy, since we cannot break down the atomic size barrier, the fact implies a fundamental size limit at the atomic or Nanotechnology scale. This means, no more simple 18 month doubling in Moore’s Law, but other forms of transistor doubling may happen at a different slope in new directions. (i) 3-D: If the progress in shrinking the in-plane dimensions (2D) is to slow down, vertical integration (3D) can help increasing the areal device transistor density and keep us on the modified Moore’s law curve including the 3rd dimension. As the devices continue to shrink further into the 20 to 30 nm range, the consideration of thermal properties and transport in such nanoscale devices becomes increasingly important. (ii) Carbon Computing: Instead of traditional Transistors, the other types of transistors material are rapidly developed in Laboratories Worldwide, e.g. IBM Spintronics bandgap material and Samsung Nano-storage material, HD display Nanotechnology, which are modifying the classical Moore’s Law. We shall consider the overall limitation of phonon engineering, fundamental information unit ‘Qubyte’ in quantum computing, Nano/Micro Electrical Mechanical System (NEMS), Carbon NanoTubes (CNTs), single layer Graphemes, single strip Nano-Ribbons, etc., and their variable degree of fabrication maturities for the computing and information processing applications.

8401-28, Session 11

Carbon nanostructures properties by terahertz time-domain spectroscopy analysis for nanoengineering applications

H. R. Lamela Rivera, E. Dadrasnia, Univ. Carlos III de Madrid (Spain)

An atomically thin layer of graphene and carbon nanotubes (CNTs) are the forefronts of research into 1-D, 2-D and 3-D dimensional of nanoengineering state-of-the-art (M. S. Dresselhaus, et al., Matter Physics, Vol 1. 2010). CNTs properties have been studied by several means such as photonic emission, scanning, microscopy, tuning fields because of the high mobility and electron transfer in terahertz (THz) frequency (P. A. George, et al., Nano Letters, vol. 8, 2008).

The analyzing and signal processing of coherent THz time-domain spectroscopy (TDS) enables the precise and simple complex permittivity for studying the properties of different thin-films over 0.1 to 10 THz (Duvillaret et al., Topics in Quant. Electron., 739, 1996). The several physical parameters of CNT have characteristic resonant frequencies within the THz range (T.-I. Jeon, et al., J. Appl. Phys. 98, 2005) .

Developing composites that are lightweight with superior thermal and electrical conductivity to improve the efficiency and reliability are main key challenges points in nanoengineering systems. CNTs can be the one of excellent candidates in nanoengineering which has shown the higher sensitivity compared to the conventional structure in different industrial applications like biomedical and security (L.Dai, Carbon nanotechnology, Elsevier, 2006). Fig.1 shows our recent experimental results on analyzing THz-TDS of the optical response conductivity of single-walled and multi-walled CNTs (H. Lamela, et al., Proceedings of SPIE. 8101-16, 2011). In this new work, we will present a comparison between the conductivity of CNTs films which allows to study the surface defects for different nanoengineering applications.

8401-29, Session 11

Optimization of high-speed pipelining in FPGA-based FIR filters using genetic algorithm

U. Meyer Baese, G. Botella Juan, The Florida State Univ. (United States); E. Castillo, A. Garcia, Univ. de Granada (Spain)

The paper compares FPGA-based full pipelined multiplierless FIR filter designs options. We compare distributed arithmetic (DA), common sub-expression (CSE) sharing, and n-dimensional reduced adder graph (RAG-n) multiplierless filter design methods in term of size, speed, and A*T product. Since DA designs are table-based and CSE/RAG-n designs are adder-based, FPGA synthesis design data are used for a realistic comparison. Superior results of a genetic algorithm based optimization of pipeline registers and non-output fundamental coefficients are shown. FIR filters based on Kastner et al. open source CSE data benchmarks for filters in the length from 6 to 152 coefficients are compiled.

8401-30, Session 11

Multiple-model particle filter: tracking target on three-dimensional space

E. P. Serrano, Univ. de San Martin (Argentina); R. O. Sirne, Univ. de Buenos Aires (Argentina); C. E. D'Attellis, Univ. de San Martín (Argentina); G. La Mura, Univ. de Buenos Aires (Argentina)

Particle Filters are Sequential Monte Carlo methods which can be applied to the estimation problem of nonlinear non Gaussian dynamic systems. As it is well known, Particle Filters rely on importance sampling and, as a result, require the design of proposal densities that can approximate the posterior density reasonably well. The choice of the proposal density is one of the most critical issues in the design and performance of the algorithm, being the most common strategy to sample from the probabilistic model of the states evolution, the transitional prior. The Multiple-Model Particle Filter (MMPF) has been proposed to perform nonlinear filtering with switching dynamic models.

In this paper we propose the use of the MMPF to the problem of tracking a target on three-dimensional space. The problem consists to estimate the trajectory (position and velocity) of the target using data given by a Doppler radar.

The estimation algorithm is tested by using simulated recorded data. The results are compared with the obtained with another filters type, as Standard Particle Filter.

8401-31, Session 11

A computational approach for statistical learning

X. Chen, Southern Univ. and A&M College (United States)

In this paper, we demonstrate that a wide class of machine learning problems can be formulated as the general problems of parameter estimation and hypothesis testing. To deduce the sample complexity associated with the learning process, we propose multistage procedures for the relevant estimation and hypothesis testing problems. A computational approach, based on the idea of branch and bound algorithms, is developed for the construction of such multistage procedures. Application examples are given for unsupervised learning problems.

8401-32, Session 11

An objective evaluation metric for color image fusion

W. Dong, The Univ. of Texas-Pan American (United States); Y. Zheng, Alcorn State Univ. (United States)

Image fusion has been extensively studied in past two decades. By image fusion algorithms, a composite image (i.e., fused image) can be formed with several images from different sensors. The performance of image fusion methods can be assessed using subjective and/or objective measures. However, subjective evaluation involves human subjects, which significantly increases the cost of time and resource. In this paper, we will discuss objective evaluations of color image fusion algorithms. Given a reference color image and fused color images, we first convert the images into CIELab color space. Then we define four image metrics in CIELab space: the phase congruency metric (PCM), the image gradient magnitude metric (IGMM), the image contrast metric (ICM), and the color natural metric (CNM). Finally, with the four metrics, we propose an objective evaluation index (OEI) for a fused image to measure its similarity with the reference image. The larger the OEI value of a fused image is, the more similar the fused image is to the reference image. To validate the proposed metric, first the fused images are formed with different color fusion algorithms using a set of multispectral images (including visible color images, near infrared images, and long wave infrared images); and then the OEIs of fused images are calculated and compared. Experimental results show that the proposed objective evaluation index is very promising and fits well to subjective evaluation.

8401-33, Session 12

Bioimaging on the nanoscale: single-molecule and superresolution fluorescence microscopy

X. Zhuang, Harvard Univ. (United States)

Optical microscopy is an essential tool in biological research. However, the spatial resolution of optical microscopy, classically limited by diffraction to several hundred nanometers, is substantially larger than typical molecular length scales in cells, leaving many biological structures unresolvable. We recently developed a new form of super-resolution light microscopy, stochastic optical reconstruction microscopy (STORM) that surpasses the diffraction limit. STORM uses single-molecule imaging and photoswitchable fluorescent probes to temporally separate the spatially overlapping images of individual molecules. This approach allows the localization of fluorescent probes with nanometer precision and the construction of sub-diffraction-limit images. Using this method, we have achieved multicolor and three-dimensional (3D) imaging of living cells with nanometer-scale resolution. In this talk, I will discuss the general concept, recent technical advances and biological applications of STORM.

8401-34, Session 13

Biomedical wellness monitoring systems with molecular markers

W. M. Ingram, The Univ. of Georgia (United States); L. Ma, H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

We wish to assist caretakers and healthcare providers with cost-effective sensor monitoring systems for tracking the physiological changes of home-alone seniors. One goal is seeking biomarkers and modern imaging methods like STORM, which has achieved visible imaging at the nano-scale range. Imaging techniques like STROM can be combined with a fluorescent functional marker in a system to capture the early transformation signs from wellness to illness by exploiting both microscopic knowledge of genetic pre-disposition and the macroscopic influence of epigenetic factors. We adopt dual spectral infrared imaging for blind sources separation (BSS) to detect angiogenesis changes and use laser speckle imaging for hypertension blood flow monitoring and the prevention of medical crises that occur at night to seniors. Our design hypothesis for the monitoring system is guided by the user-friendly, veteran-preferred “4-Non” principles (noninvasive, noncontact, non-tethered, non-stop-to-measure) and by the NIH’s “4Ps” initiatives (predictive, personalized, preemptive, and participatory). We chose smartphones as the computational and communication platform and augment them with the recent know-how of video Compressive Sampling (CSp) from surveillance Electro-Optical Infrared (EO/IR) cameras. In CSp only major changes are saved, which reduces the manpower cost of caretakers and medical analysts. This CSp algorithm is based on smart associative memory (AM) matrix storage: change features and detailed scenes are written by the outer-product and read by the inner product without the usual Harsh index for image searching. From this approach, we design an effective household monitoring approach to save healthcare costs and maintain the quality of life of seniors.

8401-35, Session 13

Opto-acoustic processing algorithms for intravascular imaging using polymer optical interferometric ultrasonic sensors

H. R. Lamela Rivera, A. Fernandez, P. Gonzalez, D. C. Gallego, Univ. Carlos III de Madrid (Spain)

OptoAcoustic Imaging (OAI) is a new biomedical imaging technology based on the use of laser-generated ultrasound. It is a hybrid modality, combining the high-contrast and spectroscopic-based specificity of optical imaging with the high spatial resolution of ultrasound imaging. It offers visualization of optical contrast in tissues, within several millimetres to centimetres, with resolutions that are typical of ultrasound imaging. As a consequence, it has greater specificity than conventional ultrasound imaging with the ability to detect haemoglobin, lipids, water and other light-absorbing chromophores,

An increasing number of optoacoustic approaches are considered for biomedical imaging. Implementations range from handheld and endoscopic operations to fixed scanner set-ups that can address a wide range of preclinical and clinical needs. In this line, in many clinical applications, high frequency ultrasounds can only be used in combination with intravascular techniques due to the high acoustic attenuation in organic tissue at tens of megahertz.

On the other hand, OAI has the goal of calculating the distribution of the optical absorption coefficient in tissues and requires computer-based reconstruction algorithms. The exact time-domain reconstruction formula produces images with excellent resolution but poor contrast. Some approximate time-domain filtered back-projection reconstruction algorithms have also been reported to solve this problem. A wavelet transform implementation using a wavelet family resembling the theoretical N-shaped OA signal can be used to sharpen object boundaries while simultaneously preserving high contrast of the reconstructed objects.

In this work, we present the ultrasonic probe of an optoacoustic intravascular endoscope based on an interferometric polymer optical ultrasonic sensor, being an important aspect the catheter design, particularly the optimization of the optical and acoustic parameters. To facilitate this process, we are developing a model to simulate the ultrasonic pressure field, generated by optical absorption in a physical phantom using an intrinsic ultrasonic optic sensor. Then, we will compare the results provided by these different approximations of OAI with real OA signals collected from the physical phantom design using the polymer ultrasonic optic sensor. Our analysis demonstrates that the image of back-projected wavelet-transformed and simultaneously integrated OA pressure signals possesses the highest contrast and adequate resolution for this OA Intravascular Imaging.

8401-36, Session 14

Further development of artificial neural networks (ANNs) for spectral interference correction in optical emission spectrometry

Z. Li, V. Karanassios, Univ. of Waterloo (Canada)

Currently, miniaturization of chemical analysis instrumentation is receiving significant attention both at conferences and the scientific literature. Due to their small size, miniaturized and thus mobile analytical instruments have significant potential for on-site analytical measurements. Also due to their small size, the have the potential to suffer from increased spectral interference effects.

In this presentation, further development [1] of algorithms for spectral interference correction using ANNs will be described in some detail. In addition, evaluation of network architectures using criteria such as training performance, training time and training epochs will be discussed and the effect of spectral-line separation in the wavelength axis will be described.

Specifically, multi-layer feed-forward back-propagation networks and one-layer adaptive networks will de described. And, neural network training and evaluation will be discussed. Furthermore, building up the architecture of a network, including layer connections, transfer function used for each layer, the number of layers, the number of neurons in each layer and selection of neural network parameters will be described in some detail. Particular emphasis will be paid to network architectures using training performance, training time, training epochs as key criteria. Furthermore, the effect of spectral resolution (e.g., spectral line separation in pm) on network performance will be outlined.

[1] Z. Li and V. Karanassios, “Development of artificial neural networks for spectral interference correction in optical emission spectrometry,” Proceedings of SPIE Vol. 8058, 80580J (2011).

8401-37, Session 14

Quantitative analysis of breast DCE-MR images based on novel empirical models

S. Goebl, Ludwig-Maximilians-Univ. München (Germany); A. D. Meyer Baese, The Florida State Univ. (United States)

DCE-MRI represents an important tool for detecting subtle kinetic changes in breast lesion tissue. Non-mass breast lesions exhibit an atypical dynamical behavior compared to mass lesions and pose a challenge to a computer-aided diagnosis system. Yet the correct diagnosis of these pre-cancerous tumors represents an important step towards early prevention. The growing number of available data requires a quick diagnosis of such lesions.

We apply the independent component analysis (ICA) on DCE-MRI images to extract kinetic tumor curves. This method is superior to the analysis of kinetic curves of complete ROIs since it filters noise out of the tumor curves. To avoid assumptions about tumor physiology, we propose to employ empirical mathematical models to distinguish between malignant and benign non-masses.

We test different empirical models ranging from phenomenological universalities to semi-parametric Bayesian splines in order to discriminate between the approximated temporal behavior of these lesions and to extract valuable kinetic features to be employed in a subsequent CAD system. Our novel methods show a significant increase in terms of successful ROC-analysis compared to state-of-the-art methods.

8401-38, Session 14

Automatic evaluation of single and joint kinetic and morphologic features for non-masses

A. D. Meyer Baese, The Florida State Univ. (United States)

The present paper describes an approach to evaluate the descriptive power of novel features describing the kinetics and morphology of non-mass lesions by an automatic hierarchic system.

A total of 46 MRI (1.5-T contrast-enhanced T1 and T2) weighted images detected lesions (22 benign and 24 malignant) with proven biopsy were selected and investigated. Lesions were rated by two board-certified radiologists. The automatic evaluation systems is hierarchically designed: the first level computes only temporal features for each pixel and creates based on these volumetric images, the second level determines shape parameters for each of these volumetric images and the last level combines the spatial features with the according kinetic features. Additionally, we employ a feature extraction to reduce the high dimension of the obtained combined morphologic and kinetic feature set and in a last step we evaluate the discriminating capability of this feature set with regard to the correct detection and classification of the benign and malignant lesions.

The best performance is achieved based on the information gain attribute evaluation which for a dimension reduction from a total feature set of 154 to 70 features is of 0.75.

The inclusion of both morphologic and kinetic features in a feature set describing non-mass lesions is necessary to capture their spatio-temporal behavior and thus represents a valuable progress towards a future CAD system.

8401-39, Session 14

How effective is kinetic, morphologic, and mixed analysis for both mass and non-mass lesions?

A. D. Meyer Baese, The Florida State Univ. (United States)

The scope of this paper is to perform a comparative analysis for the performance of temporal, morphologic and mixed feature sets describing both mass and non-mass lesions.

A total of 76 small mass and of 46 non-mass MRI (1.5-T contrast-enhanced T1 and T2) weighted images detected lesions (36 benign and 40 malignant for masses and 22 benign and 24 malignant for non-masses) with proven biopsy were selected and investigated. Lesions were rated by two board-certified radiologists. The temporal features are extracted based on a linear approximation of the last three time scans of the relative signal intensity enhancement (RSIE) for both masses and non-masses. As morphological features, we chose Minkowski functionals as shapes measures and Krawtchouk moments for masses and Zernike moments for non-masses, respectively. Krawtchouk moments are known for their descriptive power for local shape variations as it is the case with small irregular masses while Zernike moments for capturing architecture irregularities and blurred margins observed in non-masses. These features are evaluated either solely or jointly and a subsequent classification system determines the discriminative performance between benign and malignant lesions.

The temporal information extracted from RSIE is not sufficient to discriminate between malignant and benign for both small masses and non-masses. However, the spatial information of local moments yields equally good results as the mixed spatio-temporal information for small lesions while including both morphologic and kinetic features yields the best results for non-mass lesions.

8401-40, Session 14

Neurosciences meet augmented reality on the battlefield

J. C. Jenkins, J. Familoni, W. Horner, H. H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

What is the potential benefit when human brain-waves are measured with a wireless, head-mounted EEG embedded inside a baseball hat? Immense, if we can discern a hostile situation by interpreting EO/IR measurements at a distance with the non-intrusive EEG brain wave ground truth measurements. A competitive In-Laboratory Independent Research (ILIR) Basic Research Program in the Life Sciences category supports the authors in developing an Augmented Realty (AR) tool for special operation needs to discern culture-related situational awareness for counter insurgent (COIN) training. AR is not Artificial Intelligence, not Virtual Reality; but like Avatar made by the movie industry. The entire foreground, the background, and their interactions are real, but not the whole scenario. Some in-house subjects may wear the wireless baseball hat developed by Professors. Jung and Makeig of the Swartz Center for Computational Neuroscience at UCSD, who are involved in an on-going Army Neuroscience Collaborative Technology Alliance (CTA) Program. We can track the brain's functionality with imaging systems over time and space, then correlate data to human visual responses to extremely realistic imagery created in 3-D modeling and simulation software widely used by video game and movie professionals. Additional factors such as variable weather, shadowing, occlusion, turbulence and scintillation seem to have adverse effects on human perception but have been hard to represent realistically in classical perception tests, especially training videos for soldiers. NVESD has been creating extensive 3-D high resolution object and interaction libraries which can be used to generate realistic AR training videos for any scenario, viewable and testable through an Intranet test-bed. By testing a large number of users over the Intranet, brain patterns among many observers with different views of the same image can be correlated. Collaboration between UCSD and NVESD could aid in the Medical Screening field of cooperative perception (netted sensing), and could refine the perceptual boundary of 'real vs. simulation' for individual observers. If a trained observer participating in these perception tests sees something out of the ordinary, the EEG will light up at "Aha", "Startling," or "Emotional" moments on the cortex and the image sequence could be statistically analyzed to pull out distinct features that appear over time. Our ability to generate scripts from anecdotal stories of veterans shows another wellness utility of this perception test. There are about a half of returning Warriors who have not claimed the PTSD. Our application is intended to reduce the False Negative Rate of PTSD by inside out early screening. We shall investigate the PTSD disclaimers with EEG & video imaging responses. Their volubility might be revealed by their adaptability while he or she is viewing the videos in various stress levels, from "shooting a desperate baby dear running for life," toward an explicitly IED explosion blood-parts shedding scenery

8401-41, Session 15

Feature selection in bio-informatics

L. Wang, Nanyang Technological Univ. (Singapore)

In bioinformatics, there are often a large number of input features. For example, there are millions of single nucleotide polymorphisms (SNPs) that are genetic variations which determine the difference between any two unrelated individuals. In microarrays, thousands of genes can be profiled in each test. It is important to find out which input features (e.g., SNPs or genes) are useful in classification of a certain group of people or diagnosis of a given disease. In this paper, we investigate some powerful feature selection techniques and apply them to problems in bioinformatics. We are able to identify a very small number of input features sufficient for tasks at hand and we demonstrate this with some real-world data.

8401-42, Session 16

Biomedical wellness challenges and opportunities

J. Tangney, Office of Naval Research (United States)

Recent formation of Human Systems Division will be given from Tri-service viewpoint. The mission of ONR Human Bio-engineered System Division is to direct, plan, foster, and encourage Science and Technology in cognitive science, computational neuroscience, bioscience and bio-mimetic technology, physiology and biophysics, immunology, social/organizational science, training, human factors, and decision making as related to Naval needs. ONR supports comprehensively Biometrics and human activity recognition, Cognitive sciences, Computational neurosciences and biorobotics, Human factors, organizational design and decision research, Social, cultural and behavioral modeling, Synthetic biology, Training, education and human performance. Naval human sciences in the innovation and discovery programs will be reviewed. Some skill sets and cases studies will be exemplified. However, the challenges and the opportunities remain in the human sciences.

8401-43, Session 17

SAFE for PTSD: noncontact psychophysiological measure based on high-resolution thermal imaging to aid in PTSD diagnosis and assessment of treatment

B. O. Familoni, J. A. Hutchinson, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. A. Morgan III, Yale School of Medicine (United States); A. M. Rasmusson, Boston Univ. (United States); B. L. O'Kane, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Post Traumatic Stress Disorder (PTSD) sometimes develops after exposure to traumatic events such as motor vehicle accidents, rape, and war. PTSD is arguably the signature injury of the conflicts in Iraq and Afghanistan. It is a war injury without visible wounds. It disables otherwise able-bodied men and women, fractures families, destroys lives, and erodes military unit readiness and cohesion. Ultimately, it may cost the sufferer his or her life and undermine our national security. PTSD sufferers exhibit autonomic hyper-responsiveness to both neutral and trauma-related stimuli. We hypothesize that use of a non-contact and quantifiable measure of autonomic reactivity in combination with diagnostic interviews such as the Clinician-Administered PTSD Scale, will focus diagnostic interviews and facilitate efficient identification of causative disturbing traumatic experiences and prove a useful tool for tailoring subsequent exposure/cognitive treatments.Study Design: employs high resolution forward looking infrared thermal imaging of sweat-pores as a noncontact, and quantifiable measure of the sympathetic autonomic nervous system to guide diagnosis, assess response to treatment, and tease out important cues to suicidality as a PTSD comorbidity. Relevance: Improved diagnosis combined with more focused and individualized treatment should result in better outcomes for PTSD sufferers, and reduce progression toward suicide.

8401-44, Session 17

Under-dermal emulator of vascular identification

J. S. Landa, R. P. Blake, A. Rich, BriarTek, Inc. (United States); H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Over the last decade several attempts have been made to leverage advances in IR imaging made by the military into medical sensing [1]. Several promising technologies have been evaluated and thus far determined to be lacking when compared to the current standards of care based on x-ray imaging [2]. While progress has been made this general class of technology has not generated wide spread interest from the medical community. This lack of interest is discouraging especially when considering the great potential for good that would result in successfully demonstrating a truly passive tumor detection system base on thermal signatures.

Recently this team participated as part of a larger group in the development and testing of a novel class of algorithms using images from two separate IR spectrums. This spectral fusing algorithm is called the Single Pixel Blind Source Separation (SP-BSS). While our experiments showed this approach provided improvements over more traditional thermography particularly in the area of overcoming environmental noise. These promising results have motivated us to develop a method for running controlled experiments so that the equipment and algorithms can be optimized and the significant engineering challenges of frame registration, data standardization, and sensor optimization. Conducting these efforts using data from human subjects is both impractical and unwarranted at this time. What we determined was needed was a physical model that approximated not only a healthy human body but also a human body developing a tumor. This physical model also provided useful insight into the detection of objects concealed on a person. We call this dual use target an Under-Dermal Emulator.

8401-45, Session 17

Adaptive region of interest (ROI) detection and tracking for respiration measurement in thermal video

B. Kaur, U.S. Army Night Vision & Electronic Sensors Directorate (United States); J. K. Nelson, George Mason Univ. (United States); J. A. Hutchinson, T. J. Williams, B. L. O'Kane, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

In the past, respiration measurement has often been determined through contact sensors. Respiration rate is a key guide for evaluating physiological state of an individual during triage. Recent work has shown that high resolution thermal cameras can passively and remotely obtain respiration signals under controlled environmental conditions [1, 2, 3, 4, and 5]. This paper introduces an automatic end-to-end respiration signal detection approach based on statistical calculations on the image around the nostril area. The paper investigates a method to detect and track the nostril area on human face in thermal video to calculate statistical values of the pixel intensity around the nostril area and correlate the statistical values with respiration signals from a contact sensor such as transducer belt. Results are based upon data collected from 150+ subjects across two different experiments. This work provides not only a new image processing tool for tracking facial targets in thermal imagery, but also enhances our capability to provide non-contact, remote, passive, and real-time methods for measuring respiration for security and medical applications.

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8401-46, Session 17

Trans-skull ultrasonic Doppler system aided by fuzzy logic

Y. Hata, M. Nakamura, Univ. of Hyogo (Japan); N. Yagi, T. Ishikawa, Ishikawa Hospital (Japan)

In 2009 in Japan, the number of the cerebrovascular accident patients is 1,470,000, and the number of death caused by this accident is 130,000. The treatment called tPA(thromboplastinogen activator) is done to the patients within 3 hours after the stroke, which is most effective method. Thus, the prompt treatment is very important issue.

This paper describes a trans-skull ultrasonic Doppler system for measuring the blood flow direction in brain under skull. In this system, we use an ultrasonic array probe with the center frequency of 1.0 MHz. The system determines the fuzzy degree of blood flow by Doppler Effect, and it locates blood vessel. This Doppler Effect is examined by the center of gravity shift in the frequency domain. In in-vitro experiment, a cow bone (thickness 1.6-2.7mm) was employed as the skull, and three silicon tubes (4.0, 5.0 and 6.0 mm) were done as blood vessels, and bubble in water imitated blood flow. We received the ultrasonic waves through a protein, the skull and silicon tubes in order. In the system, fuzzy degrees are determined with respect to the Doppler shift, amplitude of the waves and attenuation of the tissues. The fuzzy degrees of bone and blood direction are calculated by them. The experimental results showed that the system successfully visualized the skull and flow direction, compared with the location and flow direction of the phantom. Thus, it detected the flow direction by Doppler Effect under skull, and automatically extracted the region of skull and blood vessel.

8401-47, Session 17

Human care system for heart-rate and human-movement trajectory in home and its application to detect mental disease and cognitive disorder

Y. Hata, S. Kanazawa, Univ. of Hyogo (Japan); M. Endo, N. Tsuchiya, H. Nakajima, OMRON Corp. (Japan)

Recently, daily health care has been received much considerable attention according to the increment of aging population and life style-related illness. In the health care, 24 hours monitoring is very important issue. The lifestyle-related illness increases from a custom of the daily life. The custom sometimes opens to diagnose mental disease and cognitive disorder.

This paper proposes a heart rate monitoring system for detecting autonomic nervous system by the heart rate variability using an air pressure sensor to diagnose mental disease. Moreover, we propose a human behavior monitoring system for detecting the human trajectory in home by an inferred camera. In day and night times, the human behavior monitoring system detects the human movement in home. The heart rate monitoring system detects the heart rate in bed in night time.

The air pressure sensor consists of a rubber tube, cushion cover and pressure sensor, and it detects the heart rate by setting it to bed. It unconstraintly detects the RR-intervals; thereby the autonomic nervous system can be assessed. The autonomic nervous system analysis can examine the mental disease. While, the human behavior monitoring system obtains distance distribution image by an infrared laser camera. It classifies adult, child and the other object from distance distribution obtained by the camera, and records their trajectories. This behavior, i.e., trajectory in home, strongly corresponds to cognitive disorders. Thus, the total system can detect mental disease and cognitive disorders by un-contacted sensors to human body.

8401-48, Session 17

Systems health care: daily measurement and lifestyle change

H. Nakajima, N. Tsuchiya, OMRON Corp. (Japan); T. Shiga, Omron Healthcare Co., Ltd. (Japan); Y. Hata, Univ. of Hyogo (Japan)

Super aging society has come to most of development nations especially Japan in the forefront. High aged population could socially cause the problems of nursing care while aging with health should be required. Lifestyle diseases are highly associated with cardiovascular events which play important causes of nursing care situation. The most effective and efficient resolution of lifestyle disease is to change lifestyle habits in its early stage rather than medicine and medical treatment. However, it might be tough to change lifestyle habit which has been longing in their lives. That's the reasons why it connects to disease.

In this paper, health care is discussed from the systems point of view. Firstly, what is health is discussed considering the related issues of salutogenesis, preventive medicine, and home and medical care. These activities have centered health rather than disease centric. Secondary, systems approaches are proposed and discussed by employing health management technology which provides the framework of continuous improvement processes of the target systems and its management side based on data-centric causal analysis. Additional related issues such as intelligent source are also discussed from multiple point views of causality sophistication. Case studies follow the notion with considering daily measurement of health trinity; i.e., exercise and daily activity, sleep and rest, and diet and meal. The data such as blood pressure, weight, and exercise mass can be measured and gathered daily and continuously by simple devices which can be used in ordinary life. The time serious data analysis is applied to extract causalities which could play an important role for changing lifestyle habits.

8401-49, Session 17

Fundamental matrix and planar homographies in stereo vision

C. H. Chu, Univ. of Louisiana at Lafayette (United States); Q. He, Mississippi Valley State Univ. (United States)

An image is a 2D projection of a 3D scene so that without a priori assumptions of the scene content, the only feasible way to reconstruct a scene is by analyzing images taken from different views. In a stereo vision setup, the configuration of the cameras includes the intrinsic parameters, the position and orientation of the cameras. This configuration information is encapsulated in a so-called Fundamental Matrix. Knowledge of the Fundamental Matrix simplifies many tasks, such as the search for image point matches. Given an image point in one of the images, the matching point in another image lies on the epipolar line defined as the intersection of the second image plane with the plane formed by the first image point and the two optical centers. The matching process therefore reduces to a 1D search. In practice, this epipolar line can be found from the Fundamental Matrix. The conventional method to calculate the Fundamental Matrix is from point correspondences, which often contain a large number of mismatches. The conventional algorithm relies a computationally expensive step of discarding the outlier false matches to find a few reliable matches for computing the Fundamental Matrix. The Fundamental Matrix is then used to yield further matches from constrained searches.

We investigate the use of planar homographies that relate images of planes in image pairs to recover the Fundamental Matrix. Recent results show that planar homographies can be reliably recovered from corresponding image patches. We compare our results with the conventional point correspondence-based solution.

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8402-01, Session 1

Hierarchical decomposition considered inconvenient: self-adaptation across abstraction layers

J. C. Gallagher, Wright State Univ. (United States)

No abstract available

8402-02, Session 2

Uncertainty preserving patch-based online modeling for 3D model acquisition and integration from passive motion imagery

H. Tang, The City College of New York (United States); P. Chang, Princeton Vision LLC (United States); E. Molina, Z. Zhu, The City College of New York (United States)

In both military and civilian applications, abundant data from diverse sources captured on airborne platforms are often available for a region attracting interest. Since the data often includes motion imagery streams collected from multiple platforms flying at different altitudes, with sensors of different field of views (FOVs), resolutions, frame rates and spectral bands, it is imperative that a cohesive site model encompassing all the information can be quickly built and presented to the analysts. In this paper, we propose to develop an Uncertainty Preserving Patch-based Online Modeling System (UPPOMS) toward automatic creation and update of a cohesive, geo-registered, uncertainty-preserving, efficient 3D site terrain model from passive imagery with varying field-of-views and phenomelogies. The proposed UPPOMS has the following technical thrusts that differentiate our approach from others: (1) A uncertainty-preserved, patch-based 3D model is generated, which enables the integration of images captured with mixtures of NFOV and WFOV and/or visible and infrared motion imagery sensors. (2) Patch-based stereo matching and intelligent sparse space carving are utilized, which are suitable for scenes with many low texture regions, particularly in mid-wave infrared images. (3) In contrast to the conventional volumetric algorithms, whose computational and storage costs grow exponentially with the amount of input data and the scale of the scene, the proposed UPPOMS system employs an online algorithmic pipeline, and scales well to large amount of input data. Experimental results and discussions of future work will be provided.

8402-03, Session 2

Feature-based background registration in wide-area motion imagery

Y. Wu, Temple Univ. (United States); G. Chen, Independent Consultant (United States); K. D. Pham, E. P. Blasch, Air Force Research Lab. (United States); L. Bai, H. Ling, Temple Univ. (United States)

Image registration in wide area motion imagery (WAMI) is a critical problem in layered sensing surveillance tasks. WAMI supports numerous activities including security assessment, situation awareness, and urban planning (e.g. traffic monitoring); do to the high resolution sensors. The high resolution, extremely low frame rate, and large camera motion in such WAMI videos introduce challenging constraints that are not evident in traditional image registration. In this study, we propose to use the feature-based approach for the registration of wide area surveillance imagery. Specifically, we extract SURF (Speeded Up Robust Feature) feature points for each frame. Using the SURF features, a k-d tree algorithm is adopted to match the feature points of each frame to the reference frame. Then, we use the RANdom SAmple Consensus (RANSAC) algorithm to refine the matching results. Finally, the refined matching point pairs are used to estimate the transformation between frames. The experiments are conducted on the Columbus Large Image Format (CLIF) dataset. The experimental results show that the proposed approach is very efficient for the wide area motion imagery registration.

8402-04, Session 2

Wide area motion imagery tracking

J. R. Vasquez, K. T. Salva, Air Force Research Lab. (United States)

Layered Sensing is characterized by Dr. Brian Kent (AFRL Chief Scientist) as the “appropriate sensor or combination of sensors/platforms, infrastructure and exploitation capabilities to generate that situation awareness and directly support delivery of tailored effects”. This paper will look at using open source tools (Blender, YafaRay, and Python) to build a model to help answer the question of what is the appropriate combination of sensors/platforms to solve a particular layered sensing problem. It is not practical to simply fly multiple sensors/platforms without at least a simple model to help prepare for such an endeavor. We will focus on EO Visible sensors to simplify the rendering but this work could be extended to use other rendering tools such as IRMA or Xpatch. The model will output a pinhole camera model, DTED, camera position, camera attitude, and ray-traced camera data that can be used for exploitation purposes. In this paper we plan to demonstrate our model output is exploitable by using model generated data in a projection algorithm ultimately producing valid NITF files that can be used in Pursuer or any other standard DoD light table tool. Because our model is based in software we can choose a location relevant to our customer AFRL but not a place we would normally travel such as Sadar City in Iraq.

8402-05, Session 2

Persistent electro-optical/infrared (EO/IR) wide-area sensor exploitation

A. P. Brown, Toyon Research Corp. (United States)

In this paper we present the development of algorithms and software prototypes to enable exploitation of persistent wide-area high-resolution video-rate imaging information in accordance with AFRL’s Voxelpedia concept, in which long-term statistical and syntactic learning is performed in a georegistered 3D framework. This paper includes discussion of novel algorithm development and demonstration of fully automated dense 3D reconstruction, statistical background modeling, and parallax mitigation for significantly improved automated target detection and segmentation using the Columbus Large Image Format (CLIF) data. Notably, we have demonstrated that by performing statistical background modeling in a geo-registered 3D framework, accurate registration of the background model with the current video frame is enabled, leading to revolutionary improvements in change detection (and hence moving target detection and tracking) performance. In particular, parallax is mitigated (and nearly completely removed), and apparent motion clutter (which may be caused by swaying vegetation, water surface waves, varying bistatic sun-scene-sensor illumination angle,

etc.) is effectively suppressed. Secondary technical benefits include the ability to automatically calibrate imaging sensors using flight data and rapidly create high-fidelity geo-registered 3D models of large scenes. This technology would have direct applications in deployed and current developmental wide-area persistent surveillance EO/IR sensor systems.

8402-06, Session 2

Anomaly detection driven active learning for identifying suspicious tracks and events in WAMI video

D. J. Miller, A. Natraj, The Pennsylvania State Univ. (United States); K. J. Sullivan, K. Dunn, M. Sheffler, Toyon Research Corp. (United States)

We describe a comprehensive system for learning to identify suspicious vehicle tracks observed by wide-area motion (WAMI) video sensors. Since dismounts and vehicles may travel on road networks and paths that are unknown to us, we first perform agglomerative hierarchical clustering of all spatial vehicle measurements, while applying heading constraints and Gaussian mixture hypothesis testing, resulting in spatial cells that largely capture individual road/trail segments. Next, for each track, both at the cell level (speed, heading) and track level (range, total distance, duration, average speed), extreme value statistics are computed and aggregated, to form a p-value statistic for each track. To fairly evaluate tracks that travel across different numbers of spatial cells, for all cell-level features, a single (most extreme) statistic is chosen, over all cells traveled, and used in forming the aggregate p-value. Finally, active learning of a supervised (logistic regression) track classifier is performed, based on anomaly-ranked track prioritization and ground-truth labeling by a human operator. This system has been applied to orthorectified WAMI data, with the tracks automatically extracted by Toyon Research Corporation. Our system gives promising preliminary results in highly ranking as anomalous aerial vehicles, dismounts, and traffic violators, and in learning which features are most indicative of suspicious tracks.

8402-08, Session 2

Comparison of 3D reconstruction techniques

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Layered sensing enables a synoptic view of the battle space, which creates a need to be able to process, store, and visualize large amounts of data. 3D reconstruction is the process of taking multiple two dimensional images and creating a 3D model making it easier to store and visualize large data sets. This paper will utilize the synthetic data from the SPIE 2010 paper “Open Source Layered Sensing Model” to compare 3D reconstruction techniques. Volumetric reconstruction based on VAM (1) will be compared with the classic stereo vision technique (2). Synthetic data will allow us to easily compare results because the 3D computer model will provide absolute truth on the building dimensions. To insure the algorithms function with real world data we will run both 3D reconstruction algorithms with the 2006 CLIF data. Independent of the data source we will compare 3D reconstruction accuracy along with algorithm performance.

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8402-09, Session 2

Insect vision-based, collision-avoidance system for remotely piloted aircraft

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Remotely Piloted Aircraft (RPA) are designed to operate in many of the same areas as manned aircraft; however, the limited instantaneous field of regard (FOR) that RPA pilots have limits their ability to react quickly to nearby objects. This increases the danger of mid-air collisions and limits the ability of RPA’s to operate in environments such as terminals or other high-traffic environments. We present an approach based on insect vision that increases awareness while keeping size, weight, and power consumption at a minimum. Insect eyes are not designed to gather the same level of information that human eyes do. We present a novel Data Model and dynamically updated look-up-table approach to interpret non-imaging direction sensing only detectors observing a higher resolution video image of the aerial field of regard. Our technique is a composite hybrid method combining a small cluster of low resolution cameras multiplexed into a single composite air picture which is re-imaged by an insect eye to provide real-time scene understanding and collision avoidance cues.

8402-11, Session 3

Multi-attributed network discovery: learning suspicious patterns in social network data

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As our need for actionable intelligence has grown, the quantity of data available continues to increase faster than our ability to automatically analyze and extract mission-critical information. As more sensors make their way into the field without a means for identifying suspicious patterns, they only serve to introduce more noise into the system with no measureable returns. This results in information overload for analysts forced to sift through data manually and large quantities of potentially-important data that is never processed.

When processing information about networks of individuals, places, and events, one would like to automatically detect suspects of interest based on their suspicious relationships or unusual patterns of activity. While several advances have been detecting such patterns in large networks, they require the user to specify a detailed pattern in advance. Little work has been done to discover such patterns within noisy, uncertain data, particularly when dealing with large data sets.

In this paper, we describe the problem of detecting and discovering suspect patterns in large networks of individuals, places, and events. First, we summarize the current state of the art in multi-attributed pattern matching. Second, we present approaches for learning patterns within large noisy data sets. We will describe a generative approach that focuses analysis on network structures that share a suspicious component and an expectation maximization algorithm that learns patterns at multiple levels of granularity. The paper concludes by describing how we have scaled these methods to discover suspect patterns in million-node networks.

8402-12, Session 3

Language translation of web-based content

B. Kahler, K. C. Jones, SAIC (United States)

Machine translation (MT) software today provides adequate conversion of foreign languages to one’s native tongue; however, dialects, slang, and character conversion errors result in partially unsuccessful translations. For an accurate translation, a native speaker is often required to

correct the translation by using sentence structure and word use cues to capture the true meaning. MT character conversion from Cyrillic, Asian, and Arabic languages to western characters induce errors in the translated text which can change the meaning or result in characters being associated together that do not form words. The authors present a solution using open source MT and the International Organization for Standardization (ISO) character mapping. The solution provides proper character conversion to achieve greater translation accuracy for web-based content.

8402-13, Session 3

Pattern activity clustering and evaluation (PACE) for security operations

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With the vast amount of network information available on activities of people, there is a need to explore the salient properties of data that detect and discriminate the behavior of individuals. Recent machine learning approaches include methods of data mining, statistical analysis, clustering, and estimation. We seek to explore contemporary methods in activity analysis using machine learning techniques that discover and characterize behaviors that enable adversarial intent prediction. To evaluate these methods, we describe the mathematics and potential metrics to characterize behavior. A scenario is presented to demonstrate the concept and metrics that could be useful for layered sensing behavior pattern analysis.

We leverage work published by Rhodes, Bomberger, and Zandipour [1-3] on learning and clustering approaches and explore standard contemporary clustering methods of SVM, group behaviors, and activity/entity analysis. To evaluate the performance of these methods, we develop metrics that could be useful in the analysis of behavior pattern learning. The performance evaluation would lead to methods of future information requests that can be garnered from data extraction, relations discovery, and analysis of existing data.

8402-14, Session 4

Web-based geospatial information extraction

B. Kahler, K. C. Jones, SAIC (United States)

The quantity of information publicly available on the World Wide Web today is enormous and continuously growing. Individual tools available for information retrieval and data mining are capable of extracting data based on search criteria but place a cognitive burden on the user to sift through the search results to find the information of interest. The dynamic nature of web-based information requires frequent searches to ensure that new information is not missed. Since public information is published on the web in many languages, translation into a common language is necessary to ensure that relevant data is not left out of a search. The authors discuss development of a programmatic method of collecting, analyzing and categorizing multi-lingual open source data. The discussed approach is designed to provide greater efficiency in public data searches and analysis by focusing on geospatial capabilities, visualizations, and the correlation of disparate pieces of information.

8402-15, Session 4

Layered network analysis: an approach for fusion of multi-int, textual data sources

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Researchers at the Air Force Research Laboratory's Information Directorate investigated combining multiple textual databases that consist of relational data from different data networks to determine if there is an improvement in a user's situation awareness. Currently, users manually process heterogeneous data types and are required to make mental correlations to merge databases and derive patterns in space and time across the different network types. This is because the vast majority of this data does not exist independently, as much of it is related and connected across networks. The researchers experimented with combining heterogeneous relational data types to determine the impact on situation awareness. The findings of this effort support future research to establish a layered multi-modal network analysis approach that would connect numerous data types for analysis purposes.

8402-16, Session 4

Quality-of-service sensitivity to bio-inspired/evolutionary computational methods for intrusion detection in wireless ad hoc multimedia sensor networks

W. S. Hortos, Jr., Associates in Communication Engineering Research and Technology (United States)

In previous work by the author, a cross-layer protocol approach to wireless sensor network (WSN) intrusion detection has been created with multiple bio-inspired/evolutionary computational methods applied to the functions of the protocol layers, a single method to each layer, to improve the detection performance of the protocol beyond that of one method applied to only a single layer's functions. Motivating the approach were the observations: genetic algorithms (GAs) have been used to select transmission frequencies and power levels, physical-layer functions; a self-organizing scheduling scheme, termed anti-phase synchronization, inspired by frog-calling behavior for reliable data transmission in WSNs has been applied to achieve collision-free transmissions between neighboring nodes, a MAC-layer function; swarm intelligence in the form of ant colony optimization (ACO), has been repeatedly considered for information routing among nodes, a network-layer function; artificial immune systems (AISs) and trust models of quantized data reputation have been invoked for detection of network intrusions that cause anomalies in data and fused information, functions of the application and presentation layers. The baseline WSN protocol design embeds GAs, anti-phase synchronization, ACO, and a trust model based on quantized data reputation at the physical, MAC, network, and application layer, respectively. The earlier construct, however, neglected to assess the net effect of the combined bio-inspired methods on the quality-of-service (QoS) performance for "normal" data streams. Analytic expressions of end-to-end delay and jitter, coupled with simulation results for WSNs under known intrusion attacks, are the basis for sensitivity analyses of QoS performance for normal traffic to both individual and combined bio-inspired methods of the baseline design.

8402-17, Session 4

A spider-web approach to the recovery of wireless ad hoc sensor networks damaged in destructive environments

W. S. Hortos, Jr., Associates in Communication Engineering Research and Technology (United States)

In ad hoc deployments of wireless sensor networks (WSNs) in battlefield or other hazardous environments, the network may incur the operational loss of a sufficient number of nodes to cause partitioning of the topology. The objective of this work is to develop a strategy for restoring network connectivity in response to widespread node outages through the placement of additional relay nodes. The bio-inspired approach to WSN recovery is based on the behavior of spiders in repairing webs. The proposed approach reestablishes the link connectivity required by the mission using the least number of relays while guaranteeing a certain degree of connectivity in the repaired topology. In contrast to methods that seek to form a minimum spanning tree among the partitioned sections of the damaged network, the proposed approach establishes a topology that resembles a spider web, in which the disjoint segments are positioned at the network periphery. The resulting topology displays greater connectivity than a minimum spanning tree and also achieves superior area coverage. Furthermore, the approach achieves balanced distribution of traffic among the deployed relay nodes. The recovery approach based on spider webs is extended, so that the degree of connectivity in the repaired topology is ensured to the next higher level. Both centralized and distributed versions of the bio-inspired spider-web approach are developed. Simulation results for a WSN, deployed in a hypothetical battlefield scenario, demonstrate the efficacy of the proposed spider-web recovery algorithm compared to that of an approach based on minimum spanning trees.

8402-18, Session 5

Dismount tracking and identification from electro-optical imagery

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With the advent of new technology in wide-area motion imagery (WAMI), there is a capability to exploit the imagery in conjunction with other information sources for improving confidence in detection, tracking, and identification (DTI) of dismounts. WAMI exploitation, along with other radar and intelligence information can aid decision support and situation awareness. Many advantages and limitations exist in dismount tracking analysis using WAMI; however, through layered management of sensing resources, there are future capabilities to explore that would increase dismount DTI accuracy, confidence, and timeliness. A layered sensing approach enables command-level strategic, operational, and tactical analysis of dismounts to combine multiple sensors and databases, to validate DTI information, as well as to enhance reporting results. In this paper, we discuss WAMI, compile a list of issues and challenges of exploiting the data for WAMI, and provide examples from recently reported results. Our aim is to provide a discussion to ensure that nominated combatants are detected, the sensed information is validated across multiple perspectives, the reported confidence values achieve positive combatant versus non- combatant detection, and the related situational awareness attributes including behavior analysis, spatial-temporal relations, and cueing are provided in a timely and reliable manner to stakeholders.

8402-19, Session 5

Learning and detecting coordinated multi-entity activities from persistent surveillance

G. M. Levchuk, C. Chabarekh, C. Furjanic, Aptima, Inc. (United States); A. F. Bobick, Georgia Institute of Technology (United States)

In persistent ground surveillance applications, detecting activities of people and vehicles, such as coordinated reconnaissance, meetings, ambush preparations, and material transportation and loading, is of highest importance. Yet, manual exploitation of wide area motion imagery (WAMI) is impossible due to sheer volume of the data. The automated algorithms are needed to analyze and summarize persistent surveillance inputs, bringing only most critical data to the analysts' attention.

Most existing methods for image- and video-based activity recognition rely on rich visual features and spatiotemporal shape motions to classify entities and their actions. Well-researched examples include distinguishing car types, people hand gestures and poses, and identifying interactive behavior such as present during multi-player games. However, WAMI sensors are lacking these data, providing only the ability to track vehicles and people, obtain general motion and temporal activity events, but challenging traditional methods with large amounts of irrelevant and ambiguous data.

In this paper, we present our enhanced model of multi-entity activity recognition, which operates on person and vehicle tracks, converts them into motion and interaction events, and represents activities in the form of role networks encoding spatial, temporal, contextual, and semantic characteristics of coordinated activities. Our model is flexible enough to capture variations of behaviors, and is used for both learning of repetitive activity patterns in semi-supervised manner, and detection of activities in data with large ambiguity and high ratio of irrelevant to relevant tracks and events. We demonstrate our models using activities captured in CLIF persistent wide area motion data collections.

8402-20, Session 5

CMA-HT: a crowd-motion-analysis framework based on heat-transfer-analog model

Y. Liang, Central State Univ. (United States); W. L. Melvin, Georgia Institute of Technology (United States); S. I. Sritharan, S. Fernandes, Central State Univ. (United States); O. Mendoza-Schrock, D. Barker, Air Force Research Lab. (United States)

Crowd motion analysis covers the detection, tracking, recognition, and behavior interpretation of target group from persistent surveillance video data. This project is dedicated to investigate a crowd motion analysis system based on a heat-transfer-analog model (denoted as CMA-HT for simplicity), and a generic modeling and simulation framework describes the crowd motion behavior. CMA-HT is formulated by coupling the statistical analysis of historical crowd's behavior, geographic information system, and crowd motion dynamics. The mathematical derivation of the CMA-HT model and the innovative methods involved in the framework's implementation will be discussed in detail. Using the sample video data collected by Central Florida University as benchmark, CMA-HT is employed to measure and identify the anomalous personnel or group in the video.

8402-21, Session 5

Differential profiling of volatile organic compound biomarker signatures utilizing a logical statistical filter-set and novel hybrid evolutionary classifiers

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A growing body of discoveries in molecular signatures has revealed that volatile organic compounds (VOCs), the small molecules associated with an individual's odor and breath, can be monitored to reveal the identity and presence of a unique individual, as well their overall physiological status. Given the analysis requirements for differential VOC profiling via gas chromatography/mass spectrometry, our group has developed a novel informatics platform, Metabolite Differentiation and Discovery Lab (MeDDL). In its current version, MeDDL is a comprehensive tool for time-series spectral registration and alignment, visualization, comparative analysis, and machine learning to facilitate the efficient analysis of multiple, large-scale biomarker discovery studies. The MeDDL toolset can therefore identify a large differential subset of registered peaks, where their corresponding intensities can be used as features for classification. This initial screening of peaks yields results sets that are typically too large for incorporation into a portable, electronic nose based system in addition to including VOCs that are not amenable to classification; consequently, it is also important to identify an optimal

subset of these peaks to increase classification accuracy and to decrease the cost of the final system. MeDDL's learning tools include a classifier similar to a K-nearest neighbor classifier used in conjunction with a genetic algorithm (GA) that simultaneously optimizes the classifier and subset of features. The GA uses ROC curves to produce classifiers having maximal area under their ROC curve. Experimental results on over a dozen recognition problems show many examples of classifiers and feature sets that produce perfect ROC curves.

8402-22, Session 5

Exploring point-cloud features from partial body views for gender classification

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In this paper we extend a previous exploration of histogram features extracted from 3D point cloud images of human subjects for gender classification. These images are drawn from the CAESAR anthropometric database provided by the Air Force Research Laboratory (AFRL) Human Effectiveness Directorate and SAE International. This database contains approximately 4400 high resolution LIDAR whole body scans of carefully posed human subjects. Success from our previous investigation was based on extracting features from full body coverage which requires integration of multiple camera images. With the full body coverage, the central vertical body axis and orientation are readily obtainable; however, this is not the case with one camera view providing less than one half body coverage. Assuming that the subjects are upright, we need to determine or estimate the position of the vertical axis and the orientation of the body about this axis relative to the camera. In past experiments the vertical axis was located through the center of mass of torso points projected on the ground plane and the body orientation derived using principle component analysis. Here we focus on new methods for deriving the three unknowns: two position coordinates for the axis location and one orientation angle. Because partial images depend on body shape, orientation and distance from a LIDAR camera, a closed form analytic solution is not feasible. The approach used to estimate the three unknowns in this paper is based on soft learning techniques such as genetic algorithms and neural networks. It also seeks improvements based on exploiting biometric constraints taken from the CAESAR database.

8402-23, Session 5

Exploring manifold learning techniques using CAESAR database

O. Mendoza-Schrock, Air Force Research Lab. (United States); M. L. Raymer, Wright State Univ. (United States)

Understanding and organizing data is the first step toward exploiting sensor phenomenology. What features are good for distinguishing people and what measurements, or combination of measurements, can be used to classify people by demographic characteristics including gender? Dimension reduction techniques such as Diffusion Maps that intuitively make sense [1] and Principal Component Analysis (PCA) have demonstrated the potential to aid in extracting such features. This paper briefly describes the Diffusion Map technique and PCA.

More importantly, it compares two different classifiers, K-Nearest Neighbors (KNN) and Adaptive boost (Adaboost), for gender classification using these two dimension reduction techniques.

The results are compared on the Civilian American and European Surface Anthropometry Resource Project (CAESAR) database, provided by the Air Force Research Laboratory (AFRL) Human Effectiveness Directorate and SAE International. We also compare the results described herein with those of other classification work performed on the same dataset, for completeness.

8402-24, Session 6

Robust fuzzy-rule-base framework for entity resolution

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Entity resolution is an important area of research with a wide range of applications. In this paper we present a framework for developing a dynamic entity profile that is evolved as matching entity records are discovered. In many situations a wide range of records with different attributes are available and an important issue is determining which attributes are relevant and the importance of each attribute. The proposed framework utilizes a genetic algorithm to discover a rule base of fuzzy rules that can match entities with a given error rate. Each rule consists of a premise containing a subset of attributes, associated fuzzy membership functions and a conclusion that defines the confidence of the rule. The genetic algorithm is used to generate an initial population of random fuzzy rules that are evaluated on a set of training data. The rule bases that score well on the training data are evolved using the genetic algorithm. The result is an optimized fuzzy rule base.

Initial testing of the proposed framework on an author database has shown encouraging results. The approach used for entity resolution in this framework can be extended to other applications, such as, searching for similar video files. Spatial and temporal attributes can be extracted from the video and an optimal fuzzy rule base can be evolved. A key feature of this approach is that the information value of each attribute is automatically determined and the genetic algorithm's error metric can be tuned to a particular application.

8402-25, Session 6

Robust multiplatform rf emitter localization

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This research is done to investigate a novel multi-platform RF emitter localization technique denoted as Position-Adaptive RF Direction Finding (PADF). The formulation is based on the investigation of iterative path-loss (i.e., Path Loss Exponent, or PLE) metrics estimates that are measured across multiple platforms in order to autonomously adapt (i.e. self-adjust) the location of each distributed/cooperative platform. Experiments conducted at the Air-Force Research laboratory (AFRL) indicate that this position-adaptive approach exhibits potential for accurate emitter localization in challenging embedded multipath environments such as in urban environments. The focus of this paper is on the robustness of the decentralized approach to RF-based location tracking. Experimental performance analysis in PADF environments generates multiple simultaneous mode-adaptive scattering trends. Many PADF configuration concepts are developed for purposes of investigating potential refinements in consistency, sensitivity, and robustness via the design and implementation of 4 IRIS stationary sensors as receivers and one hidden IRIS as a transmitter during the localization phase. Further pursuit of this type of PADF research shows potential for the development of PADF systems that demonstrates a degree of robustness and localization accuracy by some analytical data processes. The robustness of detecting the transmitter's position is initiated by getting the Received Signal Strength Indicator (RSSI) data through experiments and then data manipulation in MATLAB will determine the robustness of each node and ultimately that of each configuration. The parameters that are used in the functions are the mean values of RSSI, RMS values, metric, and error. The objective is to determine which configurations possess high robustness. It is observed that the robustness functions indicate that configurations that are known to be robust have high robustness values while the more sensitive configurations have lower numbers.

8402-26, Session 6

Creation of an API for sensors and servos

R. Van Hook, Air Force Research Lab. (United States) and Wright State Univ. (United States); N. Eikenberry, K. Kirke, S. Lurie, J. C. Gallagher, Wright State Univ. (United States)

Inherent in the Air Force's mission of airborne intelligence, surveillance, and reconnaissance (ISR) is the need to collect data from sensors. Technology is constantly advancing and, as such, new sensors are also being constantly produced. The manufacturers of these sensors typically provide with their hardware free software for communication with their sensor. These binaries work well for mature systems as interfaces and communication protocols are already firmly established.

However, most research software is, by its very nature, immature and typically unable to communicate with sensor packages. Because of this, researcher productivity is hindered as they have to focus on hardware communication in addition to their immediate research goals. As such, the creation of a library to talk to common sensors and other hardware is needed. This paper describes the various libraries currently available and their limitations. It also documents AFRL's effort to create a "super library" that removes as many of the limitations of each of the individual libraries as possible.

8402-27, Session 6

Micro-UAV tracking for EO exploitation

R. Van Hook, Air Force Research Lab. (United States); D. Browning, J. Matthews-Martinez, J. Wilhelm, J. C. Gallagher, Wright State Univ. (United States)

Historically, the Air Force's research into aerial platforms for sensing systems has focused on low-, mid-, and high-altitude platforms. Though these systems are likely to comprise the majority of the Air Force's assets for the foreseeable future, they have limitations. Specifically, these platforms, their sensor packages, and their data exploitation software are unsuited for close-quarter surveillance, such as in alleys and inside of buildings.

Micro-UAVs have been gaining in popularity, especially non-fixed-wing platforms such as quadrotors. These platforms are much more appropriate for confined spaces. However, the types of video exploitation techniques that can effectively be used are different from the typical nadir-looking aerial platform. This paper discusses the creation of a framework for testing existing and new video exploitation algorithms, as well as describes our own micro-UAV-based tracker.

8402-28, Session 6

Efficient, massively parallel exploration of networks by biological agents

D. V. Nicolau, Jr., Molecular Sense Ltd. (United Kingdom); D. V. Nicolau, Univ. of Liverpool (United Kingdom)

The exploration of networks with a view to discovering certain of their global properties (such as the presence of a self-avoiding circuit) is a critically important problem in a multitude of defence applications, including cryptography, logistics and other planning tasks. In most cases of interest, the appropriate mathematical problem is combinatorial and "NP-hard" and therefore computing its solution is generally intractable using conventional computers. Biological systems, on the other hand, process information only in a massively parallel fashion (e.g. hundreds of metabolic processes proceed concurrently in each living cell). One can therefore hope to harness this property of living systems to efficiently solve combinatorial problems, as has been attempted with DNA computing. In this paper we describe the design of a device that uses molecular motors or similarly sized, moving biological entities or "agents" to explore a given network or set of networks. We illustrate the potential of this purported device to solve one particularly relevant NP-hard problem in defence contexts: SUBSET SUM, which underlies many cryptography and limited-resource-allocation applications. Simulations of our design suggest that implementations of this device would perform well in comparison to conventional, electronic computers for any combinatorial task that can be encoded as a network architecture.

8402-07, Poster Session

Recovering projective structure and motion from straight lines

P. Srestasathiern, A. Yilmaz, The Ohio State Univ. (United States)

Our work introduces a new method to estimate projective structure and camera motion by minimizing 2D re-projection error from line correspondences across multiple views. In contrast to many line-based methods that use image and/or 3D line segments in cost functions, we represent both the 3D line and its images as infinite lines. Particularly, the 3D line, which is represented in the Plucker coordinates, is triangulated by back-projecting 2D lines using a novel model. In general, the Plucker constraint need to be imposed in the estimation model in order to get valid 3D line. By using the concept of dual space geometry, the Plucker constraint is waived in our 3D line estimation model. Another contribution of the proposed approach is using a line normalization scheme to improve the conditioning of the estimation. Given the initial estimates for 3D lines, their images and the camera matrices, we use the bundle adjustment framework reformulated to line projections to simultaneously estimate the structure and camera motion. The proposed cost function includes a line similarity measure that exploits the Hessian form for both image and re-projected lines. The Hessian form is a function of the angle of inclination and the distance of the line to the origin. We demonstrate the effectiveness of the proposed approach in a number of examples.

8402-10, Poster Session

Performance analysis of a track-before-detect dynamic programming algorithm based on likelihood

Z. Lin, Y. Zhou, A. Wei, National Univ. of Defense Technology (China)

The dynamic programming algorithm based on likelihood which is used in track-before-detect is proved to be very effective in detecting infrared dim target. This paper introduced the thought of probability data association (PDA) and believed that the moving state of target is predictable, and the noise is subject to uniform distribution and Gaussian distribution in predicted area. Therefore, set up state transfer function by using the distance from alternative target position to predicted position, then built merit function by the comprehensive utilization of amplitude likelihood ratio and state transfer function, and improved the calculating procedure of dynamic programming algorithm. According to Pearson theorem, under different parameters, sampled the merit function causing the state transfer function, and proved that the sampling value of merit function is subject to the normal population with the level of significance test of 0.1 by using the kurtosis and skewness test. Accordingly, the paper analyzed and deduced the probability distribution of merit function based on state transfer function and amplitude likelihood ratio, combining the calculating procedure of dynamic programming method, derived the expressions of probability distribution of merit function of noise track and target track respectively, and concluded that the results of theoretical analysis and simulation test results are consistent, and the theoretical analysis is of guiding significance to the selection of parameters in detecting the performance of such dynamic programming algorithm.

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8403-01, Session 1

Chip-scale photonic routing fabrics for avionic and satellite applications

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In recent years, avionic platforms have been moving toward a strongly integrated optical network using optical fibers and components to replace their electrical counterparts. Optical fibers provide an increased bandwidth and weight reduction in comparison to conventional electrical cabling, ultimately reducing the overall Size Weight and Power (SWaP) of the platform. Optical fibers allow high data rates between modules with low loss utilizing Wavelength Division Multiplexing (WDM); however as the number of modules increase in a network, the solution to efficiently communicate between each element becomes exponentially more difficult. To address the interconnect demands brought forth by a growing optical local area network; an optical router that can be reconfigurable to selectively connect modules through a common backplane is necessary. In this paper we present a reconfigurable bi-directional optical routing fabric using chip-scale silicon photonics. The routing fabric utilizes slow light photonic crystal waveguides as directional couplers to reduce the size of the fabric and the power requirements for reconfiguability. This architecture allows for fast, efficient, low power bi-directional routing for multiple channels in a WDM optical network

8403-02, Session 1

Optical processors using semiconductor optical amplifiers

S. Ma, W. Li, N. K. Dutta, Univ. of Connecticut (United States)

Optical latches are important for a wide range of applications including communication systems, optical logic systems, optical random access memory (RAM) and all-optical encryption. All optical latches using semiconductor optical amplifier (SOA) based Mach-Zehnder interferometer (MZI) have been studied. The building blocks of the optical latch such as XOR, AND and NOR gates have been fabricated and their operation demonstrated at ~ 80 GHz. The SOA-MZI is fabricated using hybrid integration technology. The waveguides of the MZI (which include attenuators, phase shifters, splitters) are fabricated using silica based planar lightguide circuits and the SOA is fabricated using InP/InGaAsP based semiconductor materials.

A rate equation model has been developed for SOA-MZI and it has been used to analyze the Boolean logic operation. The model has been used to analyze the Set-Reset (S-R) latch, the gated S-R latch and the D-Flip-Flop devices. The D-Flip-Flop (DFF) is the basic device for optical memory circuits.

An optical pseudo-random bit stream (PRBS) generator is important for all-optical encryption circuits. A model of a PRBS generator using SOA-MZI based devices has been developed. We show that a PRBS generator can work @ 80 Gb/s using regular SOAs and @ ~ 250 Gb/s or at higher speeds using two-photon absorption based processes in SOAs.

8403-03, Session 1

High-fidelity modeling and simulation for radar electronic warfare system concepts

C. Wu, A. Young, Defence Research and Development Canada, Ottawa (Canada)

Experience has shown that it is expensive to design, build and test military electronic warfare (EW) system hardware in a Research and Development (R&D) environment. An EW system is comprised of various sub-systems and effective integration of sub-system information while maintaining signal integrity can be difficult. In order to mitigate the problem, the HFM&S is a practical approach that includes the high-fidelity behavioural model (HFBM) of EW systems and scenarios embedded with different EW concept of operations (CONOPS). The HFM&S is also an essential way to develop EW system specifications, and should be used for a system validation and verification.

This paper presents the HFBM of a wideband digital receiver in Matlab/Simulink® and RF Toolbox/RF Blockset®, and the use of the model to build a multi-channel ESM system that has a linear antenna array. The ESM system is installed on an UAV to intercept a ground based emitter signal in a scenario that is built in Satellite Tool Kit®. Through the design and build of the UAV ESM payload and the use of this payload in a scenario, this paper demonstrates:

- What is meant by a HFBM of a system and how it can replicate real hardware in the computer?
- How the signal integrity in the HFM&S can be and should be retained?
- Why amplitude and phase are important for the signal waveform level M&S?
- Why the modern High Performance Computing technology should be used for the signal waveform M&S, and
- Why the development of a realistic scenario is an important part of the HFM&S for EW system level CONOPS development?

8403-04, Session 2

Infrared imagery acquisition process supporting simulation and real-image training

J. D. O'Connor, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The increasing use of infrared sensors requires development of advanced infrared training and simulation tools to meet current Warfighter needs. In order to prepare the force, a challenge exists for training and simulation images to be both realistic and consistent with each other to be effective and avoid negative training. The US ARMY Night Vision Electronic Sensors Directorate has corrected this deficiency by developing and implementing infrared image collection methods that meet the needs of both real image trainers and real-time simulations. The author presents innovative methods for collection of high-fidelity digital infrared images and the associated equipment and environmental standards. The collected images are the foundation for UK, US Army, and USMC real image combat ID training and also support simulations including the Night Vision Image Generator and Synthetic Environment Core. The characteristics, consistency, and quality of these images have contributed to the success of these and other programs. To date, this method has been employed to generate signature sets for over 350 vehicles. The needs of future physics-based simulations will also be met by this data. Lessons learned in the acquisition of NVESD's image database will support the development of training and simulation capabilities as Warfighter needs evolve.

8403-05, Session 2

Development of radiometrically accurate synthetic thermal infrared video for tracking algorithm evaluation

D. B. Rhodes, Z. Ninkov, Rochester Institute of Technology (United States); J. D. Newman, P. P. K. Lee, ITT Exelis Inc. (United States); G. J. Gosian, ITT Corp. (United States)

The development and testing of thermal signature tracking algorithms burdens the developer with a method of testing the algorithm's fidelity. Although collected video is normally used for testing tracking algorithms to evaluate performance in a variety of configurations. Acquiring suitable volumes of collected video data in multiple configurations can be prohibitive. As an alternative to collected video, the development of accurate synthetic thermal infrared vehicle models are incorporated into background infrared scenes generated using the Digital Image and Remote Sensing Image Generation (DIRSIG) software package. Additional software models for thermally emissive targets and motion are being implemented. The goals are to accurately incorporate thermal signatures of moving targets into realistic radiometrically calibrated scenes. This aids in evaluating tracking algorithms using both visible and thermal infrared signatures for improved day and night detection capability. The software packages are integrated together to produce synthetic video.

8403-06, Session 2

Software for multimodal battlefield signal modeling and optimal sensor placement

K. K. Yamamoto, S. Vecherin, D. K. Wilson, U.S. Army Engineer Research and Development Ctr. (United States); C. Pettit, U.S. Naval Academy (United States)

Effective use of passive and active sensors for surveillance, security, and intelligence must analyze terrain/atmospheric effects on multimodal sensor performance. Several years ago, U.S. Army ERDC undertook a project to develop software that models such effects on target signatures, signal propagation, and battlefield sensors for many signal modalities (e.g., optical, acoustic, seismic, magnetic, radio-frequency, chemical, biological, and nuclear). Since its inception, the software (called Environmental Awareness for Sensor and Emitter Employment) has matured and evolved significantly for simulating a broad spectrum of signal-transmission and sensing scenarios.

EASEE efficiently integrates diverse signal-propagation, processing, and sensor models for multiple modalities using highly flexible, object-oriented definitions of the general stages, or "building blocks," of a sensing problem, including signal generation, propagation, reflection, sensing, processing, and fusion. These building blocks are implemented within platform objects representing various battlefield entities (e.g., ground vehicles, unattended aerial systems, radar/lidar systems, acoustic/seismic sensors, and humans), which are linked with one another to model complex, multimodal passive- and active-sensing scenarios.

An sensor placement algorithm has also been built in for optimizing sensor selections (e.g., acoustic, seismic, RF, line-of-sight, etc.) and placements based on specification of sensor supply limitations, coverage priorities, and overlapping sensor coverage and wireless sensor communication requirements. The algorithm runs EASEE's advanced models for atmospheric and terrain effects on target signatures and signal propagation.

The EASEE Java-language library is embeddable in a variety of mission planning and geospatial information systems and also available as a standalone Windows program.

8403-07, Session 3

Dealing with performance/portability and performance/accuracy trade-offs in heterogeneous computing systems: a case study

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The benefits of using heterogeneous computing systems for high-performance computing are recognized by the scientific community. Significant performance gains can be achieved by using GPUs for numerous scientific applications. Still scientists have to deal with two key trade-offs, between performance versus portability and between performance and accuracy.

The choice of parallel programming language, CUDA or OpenCL, can impact the performance versus portability trade-off. CUDA supports greater performance on Nvidia GPU's but is limited to running on this vendor's GPU's. OpenCL is cross-platform but not as highly developed and thus suffers in the performance aspect.

The choice of single or double precision for computations can impact the performance versus accuracy trade-off. GPU's have a significant advantage over CPU's in single precision performance but a smaller advantage when it comes to double precision and not all GPU's have double precision support. However a large number of computing tasks require the accuracy provided by double precision.

In this work we present the study of these two important trade-offs for a relevant linear algebra problem, matrix multiplication modulo a prime. Integer matrix linear algebra methods rely heavily on matrix multiplication modulo primes. Double precision is necessary for exact representation of sufficiently many primes. We examine the performance losses due to the use of OpenCL versus CUDA and the use of double versus single precision. Our results indicate that performance losses from the former are negligible and from the latter are acceptable when double precision is required.

8403-08, Session 3

Sparse matrix solutions for graphics processing units

K. Spagnoli, J. R. Humphrey, Jr., D. Price, E. J. Kelmelis, EM Photonics, Inc. (United States)

The modern graphics processing unit (GPU) found in many standard personal computers is a highly parallel math processor capable of over 1 TFLOPS of peak computational throughput at a cost similar to a high-end CPU with excellent FLOPS-to-watt ratio. High level sparse linear algebra operations are computationally intense, often requiring O(N3) operations and would seem a natural fit for the processing power of the GPU.
The GPU execution model featured by NVIDIA GPUs based on CUDA demands large-scale parallelism to achieve good performance, requiring between hundreds and thousands of simultaneous operations. Some constructs from linear algebra map extremely well to the GPU and others map poorly. CPUs, on the other hand, do well at smaller order parallelism and perform acceptably during low-parallelism code segments. Our work addresses this disparity via hybrid a processing model, in which the CPU and GPU work simultaneously to produce results. In many cases, this is accomplished by allowing each platform to do the work it performs most naturally. For example, the CPU is responsible for graph theory portion of the direct solvers while the GPU simultaneously performs the low-level linear algebra routines. We present results from both direct and iterative sparse system solvers.

8403-09, Session 3

ArrayFire: a GPU acceleration platform

G. Pryor, AccelerEyes LLC (United States)

GPUs have been shown to be greatly beneficial to several areas of research including, but not limited to, defense, medical imaging, meteorology, and finance. However, these devices remain difficult to program and even more difficult to optimize. We present ArrayFire, a software library for AMD, Intel, and NVIDIA GPUs that includes a memory manager, runtime, and an array datatype for scientific computing that abstracts away the GPU programming difficulty. Provided with the array data type are a series of scientific methods falling into the categories of reductions, statistics, inclusive scan, set operations, element wise operations (arithmetic, logical, unary, binary, etc), basic linear algebra (matrix multiply, dot product, matrix norm, vector norm, etc), dense linear algebra, image processing, signal processing, and array operations (flip, rotate, etc). The array datatype may also be reshaped, subscripted, concatenated, and split utilizing vectorized notation. ArrayFire also provides a loop construct, gfor, for the batch processing of large data sets. ArrayFire also provides a mechanism for multi-gpu support, gselect. ArrayFire is built using CUDA and OpenCL with frontend language support for M (available in MATLAB), C, C++, Fortran, and Python. We provide bechmarks on a series of problems and GPUs showing the achievable performance of the platform.

8403-10, Session 3

A novel approach for effectively programming hybrid HPC platforms

J. R. Humphrey, Jr., K. Spagnoli, D. Price, E. J. Kelmelis, EM Photonics, Inc. (United States)

Hybrid systems consisting of traditional compute nodes as well as nodes augmented with massively parallel accelerators are rapidly becoming commonplace in the supercomputing scene. Presently three of the top five supercomputers in the world are of such an architecture. Effectively utilizing these systems has been an area of research, and most of the solutions proposed to date are only relevant to a single codebase or computing technique, and so the rate of programmer adoption of hybrid machines for supercomputing applications has been slow. The principal challenge lies in the fact that the accelerator add-on imposes an additional level of programmer concern, and issues such as manually managing the accelerator's memory space become burdensome and then must be re-evaluated upon the arrival of each new generation of hardware. In our work, we build upon a technique from when NUMA machines were commonplace, which is to express a program as a series of work tasks and the data dependencies that are required to execute that task. From there, our software then creates an efficient execution plan and then dispatches the work appropriately to the cluster elements. We will show how this approach is again applicable and overcomes the difficulties in hybrid computing.

8403-11, Session 4

Constraints on first order Markov Chain models of spectrally decomposed road profiles

P. A. Chin, J. B. Ferris, Virginia Polytechnic Institute and State Univ. (United States)

Road profiles are a major excitation to the chassis and the resulting loads drive vehicle designs. However, the resources required to simulate large sets of measured, spectrally broad, roads is often infeasible. This motivates the need for more accurate models for characterizing roads and generating synthetic road profiles. Modeling techniques such as power spectral density and Markov Chains have been proposed; specifically, first order Markov Chains were developed for measured data that were spatially differenced. However, this method is unreliable when synthesizing road profiles due to the lack of low frequency content in the differenced data from which the model was derived. Presently, this work addresses the issue by modeling road profiles as a combination of several spectrally-decomposed sets of data that are individually modeled by first order Markov Chains. The proposed methodology is formulated as a constrained parameter and likelihood ratio model comparison problem: Given the number of Markov Chain states (or quantization reconstruction levels) to be applied and cut-off frequencies that spectrally decompose measured data into high and low passed parts, find the spectral region of a road profile where the first order Markov property holds. A series of pre-existing statistical tests, based on the log-likelihood ratio and χ^2 distribution, quantifies the confidence that the required first order Markov Chain properties are met. This hybrid modeling process is demonstrated on profile data taken at the Virginia Tech VTTI and Danville, Virginia locations with longitudinal resolution of 25 mm and a vertical resolution of 1 mm. This advancement in characterizing road profiles is evidenced in the generation of synthetic profiles and comparison to previous methods.

8403-12, Session 4

Analysis of special nuclear material (SNM) detection and interdiction using a collaborative constructive simulation environment

L. A. Hendrix, R. Mayo, R. West, The Johns Hopkins Univ. Applied Physics Lab. (United States)

The acquisition of systems to locate and interdict Special Nuclear Material (SNM) is significantly enhanced when trade space analysis of and CONOPS development for various proposed sensor systems is performed using realistic operational scenarios in a synthetic simulation environment. To this end, the U. S. Defense Threat Reduction Agency (DTRA) has developed a collaborative constructive simulation environment hosted at the Defense Threat Reduction Center at Ft. Belvoir, VA. The simulation environment includes a suite of modeling and simulation (M&S) tools, scenario vignette representations, geographic information databases, and authoritative sensor system representations. Currently, focused on modeling the detection and interdiction of in-transit SNM, the M&S tools include the Monte Carlo N-Particle (MCNP) simulation for detailed nuclear emissions calculations and the JHU/APL enhanced Joint Semi-Automated Forces (JSAF) synthetic simulation environment and several associated High-Level Architecture (HLA) federate simulations for engagement-level vignette executions. This presentation will focus on the JHU/APL enhancements to JSAF which have enabled the execution of SNM detection vignettes. These enhancements include the addition of a user-configurable Radioactive Material (RM) module for representation of SNM objects, a user-configurable RM Detection Module to represent operational and notional gamma and neutron detectors, a RM Attenuation Module to calculate net emissions at the detector face in the dynamic JSAF environment, and a RM Stimulation Module to represent notional proton and photon beam systems in active interrogation scenarios.

8403-13, Session 4

Massively scalable computational fluid dynamics solvers for hybrid supercomputing platforms

D. Hertenstein, J. R. Humphrey, Jr., A. L. Paolini, E. J. Kelmelis, EM Photonics, Inc. (United States)

EM Photonics has been investigating the application of massively multicore processors to a key problem area: computational fluid dynamics (CFD). Fluid solvers are among the most important applications

that are run on supercomputers and on individual developer machines, consuming countless processing hours per year. The capabilities of the CPU to solve these problems have been increasing steadily, but the CPU is still a general-purpose device designed to run diverse applications such as word processors and internet browsers - it is not a high performance device for scientific computing. One of the emerging technologies in high-performance computing is the graphics processing unit (GPU); driven by market leader NVIDIA, the GPU has become a highly respected platform for computing. EM Photonics has been working to increase the speed of the popular FUN3D package which was created by NASA and is widely used in defense, commercial, and research applications. The result is a many fold improvement in performance, granting better resolution results in less time without sacrificing accuracy. Scaling solvers beyond a single-CPU, single-GPU configuration can be quite challenging; in this case the solver's architecture was well suited to CPU parallelism, but challenging for GPU. In this talk, we will address these challenges.

8403-14, Session 4

Data models as a general, fast framework for converting simulations at all scales into fast, real-time approximations

H. M. Jaenisch, J. W. Handley, Licht Strahl Engineering, Inc. (United States)

Data Modeling is a process that can convert non-real-time algorithms into functional approximations that can be executed in near real-time as platform independent mathematical equations of information transfer functions. These functional approximations are converted into a form amenable for streaming real-time execution by being converted into pre-calculated look-up table (LUT) form. We present the technique and relevant theory and demonstrate how this method can be applied high level interactions, system level modeling and component modeling using a common framework. An important benefit of our technique is the ability to predict anomalous parameters from our derived models.

8403-15, Session 4

A methodology for designing modeling and simulation (M&S) that integrates verification, validation, and accreditation (VV&A) processes and documentation

J. N. Elele, N. M. Gould, Naval Air Systems Command (United States)

This paper will present a method that integrates Modeling and Simulation (M&S) Verification and Validation as part of the M&S design. In the past, very few models were developed with Verification, Validation, and Accreditation (VV&A) as part of the design process. In a large number of cases VV&A was done, if at all, after the model had already been released to the user community and was already being used by major programs to support major decisions. This has changed in recent years as declining resources have resulted in a growing reliance on M&S. As awareness of the issues and the risks involved has increased, Dept. of Defense (DoD) policies have been written that require VV&A to be integrated into the M&S design and development early in the process. Many things can go wrong when a model is not carefully verified and validated. Not only does lack of V&V make a model difficult, if not impossible, to use, but the model may fail to support its intended use (as defined by the user or sponsor). VV&A reduces the risks of developing an M&S that does not meet requirements or of using an inappropriate simulation to support a decision. While risks can never be eliminated entirely, they can be quantified in a way that allows optimal decisions to be made. This paper will include some description of the risks associated with model development, which forms the basis for the new DoD policies.

8403-16, Session 5

An analyctical approach to air defense: cost, effectivness, and SWOT analysis of employing fighter aircraft and modern SAM systems

O. Kus, Turkish Air Force (Turkey); I. Kocaman, Y. Topcu, Turkish Air Force (United States)

The problem of defending a specific airspace is among the main issues a military commander is to solve. Proper protection of own airspace is crucial to mission success at the battlefield. The military doctrines of most world armed forces involve two main options of defending the airspace. One of them is utilizing formations of fighter aircraft, which is a flexible choice. The second option is deploying modern SAM (Surface to Air Missile) systems, which is more expansive. On the other hand the decision makers are to cope with miscellaneous restrictions such as the budgeting problems. This study presents a SWOT (Strenghts - Weakness - Opportunities - Threats) analysis of deciding up weather fighter aircraft or modern SAMs for airspace defense is a better option. We conclude that deploying SAMs has important advantages over using fighter aircraft.

8403-17, Session 5

Software as a service approach to sensor simulation software deployment

S. Webster, KINEX Inc. (United States); G. J. Miller, Oakwood Controls Corp. (United States); G. Mayott, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Traditionally, military simulation has been problem domain specific. Executing an exercise currently requires multiple simulation software providers to specialize, deploy, and configure their respective implementations, integrate the collection of software to achieve a specific system behavior, and then execute for the purpose at hand. This approach leads to rigid system integrations which require simulation expertise for each deployment due to changes in location, hardware, and software. Our alternative is Software as a Service (SaaS) predicated on the virtualization of Night Vision Electronic Sensors (NVESD) sensor simulations as an exemplary case. Management middleware elements layer self provisioning, configuration, and integration services onto the virtualized sensors to present a system of services at run time. Given an Infrastructure as a Service (IaaS) environment, enabled and managed system of simulations yields a durable SaaS delivery without requiring user simulation expertise. Persistent SaaS simulations would provide on demand availability to connected users, decrease integration costs and timelines, and benefit the domain community from immediate deployment of lessons learned.

8403-18, Session 5

Enhancing army analysis capability for war fighter protection: TRADOC-RDECOM M&S decision support environment collaboration

K. Athmer, C. Gaughan, U.S. Army Research Lab. (United States)

The Army is currently confronting significant challenges in developing an Integrated Base Defense (IBD). The IBD problem space has a large number of stakeholders that include the Assistant Secretary of the Army for Acquisition, Logistics and Technology ASA(ALT) Office of the Chief Systems Engineer, Training & Doctrine Command (TRADOC) and Research, Development and Engineering Command (RDECOM) organizations. In order to evaluate IBD decisions, the TRADOC Maneuver Support Center of Excellence (MSCoE) led and continues to lead a series of IBD focused experiments. Modeling and Simulation (M&S) significantly contributes to this effort. In order to fill M&S capability gaps, a collaborative demonstration with RDECOM's M&S Decision

Support Environment (MSDSE) was held in September 2011. The results of this demonstration provided key input to MSCoE IBD studies and critical technologies for IBD. The event showcased an innovative application of Science & Technology (S&T) M&S across the Army. The IBD effort established a simulation tool that will significantly improve force protection in combat zones and Army installations worldwide by providing leaders a tool to conduct analysis of defense and mission rehearsals.

The event was executed with a “human in the loop” Battle Captain, who was aided by mission command assets such as Base Expeditionary Targeting and Surveillance Sensors-Combined (BETSS-C). The Common Operating Picture was populated and stimulated using S&T M&S capabilities, allowing for a realistic representation of physical phenomena without the need for real systems. Novel methods were used for simulation orchestration, for initializing the simulations, and for initiating Opposing Force (OPFOR) activities. Ultimately, this event demonstrated that the MSDSE is suitable to support TRADOC IBD analyses, that S&T M&S is ready to be used in a demanding simulation environment, and that RDECOM can provide additional M&S capabilities to enable the MSCoE.

8403-20, Poster Session

COMBAT: mobile-Cloud-based cOmpute/oMmunications infrastructure for BATtlefield applications

T. Soyata, R. Muraleedharan, S. Ames, J. H. Langdon, C. F. Funai, Univ. of Rochester (United States); M. Kwon, Rochester Institute of Technology (United States); W. B. Heinzelman, Univ. of Rochester (United States)

The amount of data processed annually over the Internet has crossed the zetabyte boundary, yet this Big Data cannot be efficiently processed or stored using today’s mobile devices. However, advances in mobile access and cloud computing have brought the state-of-the-art in mobile-cloud computing to an inflection point, where the right architecture may allow mobile devices to run applications utilizing Big Data. In this paper, we propose the MObile Cloud-based Hybrid Architecture (MOCHA), which formulates a solution to permit mobile-cloud computing applications such as object recognition for battlefield support and encompasses a hardware/software framework utilizing innovative algorithmic approaches. MOCHA is built on the key observation that many mobile-cloud applications have the following characteristics: 1) they are compute-intensive, requiring the compute-power of a supercomputer, and 2) they use Big Data, requiring a communications link to cloud-based database sources in near-real-time. MOCHA outlines the necessary components to support this by: 1) incorporating an intermediate GPU-based cloudlet layer between the mobile and the cloud, 2) formulating optimal communications and dynamic task-partitioning strategies among the mobile, the cloudlet, and the cloud, and 3) incorporating a GPU-based compute cluster that provides the compute-power that these applications need. The aforementioned cloudlet and cloud layers could, for example, be housed within a soldier’s vest and inside a military vehicle, respectively, effectively decoupling the compute and communications portion of the application. The MOCHA platform for mobile-cloud computing promises a future for critical applications that access Big Data, which is currently not possible using existing technology.

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8404-01, Session 1

STER: a look at sensor-triggered communication for wireless networks

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Wireless sensor networks (WSN) have become powerful tools for gathering and monitoring environmental data. These networking systems can be utilized for many different applications due to their autonomy, ability to withstand harsh conditions, and the reduced cost associated with their collection of data. These characteristics are beneficial across a wide range of applications including those specific to the military, environmental, industrial, and medical industries. Additionally, they become increasingly more relevant in remote sensing applications where size weight and power trade-offs are of particular importance. Conversely, these applications also demonstrate the Achilles heel of a large percentage of WSNs in that they run on limited power sources. Thus, energy efficiency is a major concern and therefore a significant amount of research has been dedicated to identifying methods of making WSNs as energy efficient as possible. The purpose of this paper is to detail a reactive wireless sensor network protocol that will minimize network overhead and energy consumption in an effort to provide longevity to the overall network. The underlying components of the Sensor-Triggered Efficient Routing protocol, STER, will be covered and the asynchronous handshaking method used to transmit data between the sending and receiving nodes will also be described. The power consumption performance results of STER will then be compared to those obtained from other protocols in the current literature. The data will show that implementation of the STER protocol should result in a wireless sensor network with an increased life span.

8404-02, Session 1

Prototype rf sensing platform for wireless sensor networks

C. R. Barber, R. R. Selmic, Louisiana Tech Univ. (United States)

Position Adaptive Direction Finding (PADF) is a method where Micro Aerial Vehicles (MAVs) equipped with wireless sensor nodes adjust their positions in real time in order to localize a hidden cooperative emitter (known protocol and frequency of operation). There is a need to extend such work and use similar approach in cases when there is limited knowledge about the hidden emitter (unknown frequency or protocol).

This paper describes the research and development results in designing a RF sensing system that can detect an unknown emitter. The paper describes system design, development and integration of a prototype RF sensing board for the IRIS wireless sensor network platform that can be used for detection, monitoring, and localization of emitters in diverse RF propagation environments. Decoupling the dependency of the received signal strength (RSS) measurements from the primary transceiver by the addition of a secondary receiver provides for a continuous real-time analysis of the RF environment signal levels. The challenge is to provide a primitive, distributed, spectrum analysis in real time using mobile sensor nodes, that is energy efficient, has small form-factor, and does not degrade the omni-directional operation of the primary node's antenna. Such distributed spectrum sensing will be able to provide accurate RSS information about non-coherent signals present in the sensing environment without the overhead of having to handle bidirectional communication to other nodes. The platform will be developed, tested, and employed on static and mobile IRIS nodes for evaluation of RF sensing performance.

8404-03, Session 1

Distributed parameter estimation in wireless sensor networks using fused local observations

M. Fanaei, M. C. Valenti, N. A. Schmid, West Virginia Univ. (United States)

The goal of this paper is to reliably estimate some parameters associated with an underlying function at a fusion center of a wireless sensor network based on its noisy samples made at distributed local sensors. A set of noisy samples of a deterministic or random function from a known class on shapes characterized by a limited set of unknown parameters to be estimated is observed by distributed sensors. The parameters to be estimated can be some attributes associated with the underlying function, such as its hight or variances in different directions, or even the weights of its specific components over a predefined basis set. Each local sensor processes its local observation and sends its processed data to a fusion center through parallel impaired communication channels. Local sensor processing typically involves an appropriate quantization of the noisy observation. Different channel models between the local sensors and fusion center are considered, including additive white Gaussian noise (AWGN) channels and discrete memoryless channels (DMC). The fusion center will then combine all of the received locally-processed observations, and estimate the unknown parameters of the underlying function. The fusion center can use different well-known estimation techniques, including maximum-likelihood (ML) and expectation maximization (EM) estimation. The estimated parameters can then be used in detection and classification of the underlying object that has created the observed influence field intensity function. The main contribution of this paper is a formulation of distributed parameter estimation in the context of wireless sensor networks, where local samples are not made from the same observed underlying parameters to be estimated. The performance of the proposed parameter estimation system is investigated through practical scenarios.

8404-04, Session 1

Routing in wireless ad hoc and sensor network underground with sensor data in real time

E. Odei-Lartey, I. K. Hartmann, H. Ahmadian, Univ. Siegen (Germany)

Wireless ad hoc network deployed underground for retrieving data in real-time, during an in-situ soil mixing drilling process, in place of the usual cabling. Each drilling tube is designated as a node consisting of two transceivers, a micro-controller and power supply wired together. During the drilling process, tubes or pipes are attached to each other in an end to end formation as drilling progresses deeper into the ground. Each transceiver is placed near the ends of the tubes in both directions of the drilling tubes. The distance between adjacent transceivers in two adjoining pipes is approximately 300millimeters and the transceivers operate at a frequency of 868MHz (off-the-shelf components to provide a cheap data communication solution in the in-situ soil mixing process). At such close proximity, there is a line of sight between these two transceivers in the adjoining pipes thus enabling wireless connectivity between adjacent nodes within the ground. A routing process which is a modification of the Advanced On-Demand Directional Vector (AODV) routing protocol is designed to route data from the sensor node in the drill head to the ground station over the wireless ad hoc network deployed underground. Each micro-controller holds unique id's for each of the two transceivers. On startup or initialization, the micro-controller of the first node pipe configures the transceivers with the respective

transceiver ID. The transceiver then listens for data packets from the pipe to which it is being connected to. Upon reception of the packet it sends it sends it via UART to the micro-controller which writes the transceiver ID of the sending node along side its RSS value to the Transceiver. It then does the necessary data processing and passes on the data to the other connected transceiver for transmission over the wireless link. The next adjoining pipe then initializes in the same way as the first upon receiving this packet. This process continues for each tube which is affixed to this string setup during the drilling process to enable for communication over the wireless ad hoc network. Data is then transmitted over this network to the ground-station to enable for control or effective monitoring of the drilling process. Communication will be bi-directional to enable for specific commands to be used to retrieve information from the sensor node in the drill head. Tubes are made intelligent to adapt for effective data communication.

8404-05, Session 1

Distributed geolocation algorithm in mobile ad hoc networks using received signal strength differences

S. Guo, H. Y. Tang, Defence Research and Development Canada, Ottawa (Canada)

Military wireless communication in battlefield is mobile ad hoc in nature. The ability to geolocate and track friendly forces and enemies are equally important in military command and control operations. However, current mobile ad hoc network (MANET) has no capabilities to geolocate radio emitters that belong to enemy's mobile ad hoc networks. This paper presents a distributed geolocation algorithm using received signal strength differences to geolocate enemy's radio emitters by leveraging friendly force's own MANET infrastructure, and proposes a communication protocol for radio emitter geolocation applications. Enemy's radio emitter signal is detected, and its signal strength is measured by the nodes in a friendly mobile ad hoc network; the identity of enemy's radio emitter is extracted from decoded header of medium access control layer messages. By correlating and associating the enemy's radio emitter identity with its received signal strength, enemy's radio emitters are identified. The enemy's radio emitter identity and its received signal strength are distributed and shared among friendly mobile ad hoc nodes. Using received signal strength differences, a master friendly node can calculate enemy's radio emitter geolocation, and build a recognized MANET picture (RMP). This MANET picture is then distributed to all friendly nodes for effective command and control operations. An advantage of this method is that mobile ad hoc nodes do not need special direction finding antennas to geolocate enemy's radio emitters as conventional electronic warfare techniques do. MATLAB-based simulations are presented to evaluate the accuracy and reliability of the proposed distributed geolocation algorithm under different MANET placements.

8404-06, Session 1

Effects of energy harvesting on quality-of-service in real-time, wireless sensor networks

W. S. Hortos, Jr., Associates in Communication Engineering Research & Technology (United States)

Quality of service (QoS) metrics for each sensor type in a wireless sensor network (WSN) of resource-constrained nodes can be associated with the metrics for multimedia that describe the quality of fused information, e.g., throughput, delay, jitter, packet loss, packet error rate, information correlation, etc. The QoS metrics depend on the performance of the network protocol layers, motivating a comprehensive cross-layer design approach to QoS optimization for multiple sensor types in a general WSN.

For more than a decade, techniques to extend the operation of battery-powered wireless sensor nodes by harvesting the energy available within the surrounding environment have been studied. Available energy sources may be thermoelectric, solar radiation, wind, electromagnetic, etc., depending on the mission. Recent advances have improved the efficiency of energy-harvesting methods to the point where they are being considered to power sensor nodes, following depletion of battery reserves. While the primary objective of energy harvesting is to prolong network lifetime, it may result in lower values for other QoS metrics. Based on the author's previous work, cross-layer protocol interactions are represented through a set of concatenated parameters and resource levels for a real-time WSN under energy harvesting (EH-WSN). The cross-layer parameters that determine QoS values in an EH-WSN are established in terms of solutions to stochastic dynamic programming conditions derived from multivariate point-process (MVPP) models of transient data and fused information flows; these values are compared to the QoS values for a battery-powered WSN of identical structure.

Simulation results from scenarios for a solar-powered WSN and for a wind-powered WSN demonstrate that the extent to which QoS values are degraded in the EH-WSNs compared to a battery-powered WSN of the same structure.

8404-07, Session 2

New space-time codes for coherent transmission scheme using multiple antennas

X. Chen, E. L. Walker, Southern Univ. and A&M College (United States)

In scenarios where channel state information is available to the receiver, making use of the information in detection significantly improves system performance. Such transmission scheme is called coherent detection. In this work, we propose a new family of space-time codes for coherent detection schemes in a wireless environment using multiple transmit and receiver antennas. The decoding problem can be efficiently solved by our parallel sphere decoder algorithm. A combination of Genetic algorithms and gradient descendent algorithms is established for the code optimization. Our simulation results indicate that such a wireless communication technique is suitable for sensing systems for reliable transmission of high volume of data.

8404-08, Session 2

Detection of code spreading OFDM based on 0-1 integer quadratic programming

A. A. Elghariani, M. D. Zoltowski, Purdue Univ. (United States)

Code Spread OFDM (CS-OFDM) provides diversity advantage when employed over multipath channels compared to conventional OFDM. To effectively benefit from this advantage an optimum detection technique such as Maximum Likelihood (ML) should be used, but because of its computational burden that results from enumerating all possible solutions it deemed impractical. Therefore, employing an optimal detection technique without searching through all possible solutions is required to get reduced complexity and improved frequency diversity.

In this paper, we introduce Mixed Integer Quadratic Programming (MIQP) approach to optimally detect QPSK Code Spread OFDM (CS-OFDM) by formulating the problem as a combinatorial optimization problem with all variables constrained to be integers in the set {0, 1}. The Branch and Bound (B&B) algorithm is utilized to solve this integer quadratic programming problem. Furthermore, we propose combined preprocessing steps to be applied prior to B&B. The first step in this combination is to detect the possible symbols using procedures presented by Pardalos et al. This procedures depend essentially on finding the range of the gradient of the quadratic function f(z) denoted by ∇f(z). Then based on the claim that minimizing f(z) is the same as minimizing (∇f(z))' * z , in addition to considering the special case of 0 and 1 where zi^2=zi and checking the sign change of ∇f(z) whether it is increasing or decreasing, one can force some variables to be zeros or ones. Then the second step is to take the undetected symbols and pass

them through MMSE estimator. This MMSE solution will be used to find the objective function value, which feeds the B&B algorithm as the initial upper bound. The choice of upper bound based on this idea proves to be a good upper bound as several nodes in the B&B tree are pruned quickly especially at high signal to noise ratio.

Simulation results show that the proposed preprocessing combination when applied prior to B&B provides optimal performance with significantly reduced computational complexity. For instance, applying B&B alone requires, on average, solving 40 nodes per group (group here means 8 variables need to be solved) but when preprocessing procedures are carried out prior to B&B, the number of nodes goes down from 40 to 4 nodes per group.

8404-09, Session 2

Adaptive compressed channel estimation: tracking from a Bayesian perspective

C. Chen, M. D. Zoltowski, Purdue Univ. (United States)

In Orthogonal Frequency Division Multiplexing (OFDM) systems, the technique used to estimate and track the time-varying multipath channel is critical to ensure reliable, high data rate communications. It is recognized that wireless channels often exhibit a sparse structure, especially for wideband and ultra-wideband systems. In order to exploit this sparse structure to reduce the number of pilot tones and increase the channel estimation quality, the application of compressed sensing to channel estimation is proposed. In this article, to make the compressed channel estimation more feasible for practical applications, it is investigated from a perspective of Bayesian learning. Under the Bayesian learning framework, the large-scale compressed sensing problem, as well as large time delay for the estimation of the doubly selective channel over multiple consecutive OFDM symbols, can be avoided. In addition, the time-varying channel can be tracked naturally by iteratively updating the maximum likelihood function of the channel impulse response. Finally, as a by-product of the Bayesian framework, adaptive channel estimation is enabled in two different ways: (1) the number of pilot tones required for reliable channel estimation can be determined adaptively and (2) the location of pilot tones in frequency domain can be selectived on the fly. Simulation studies show a significant improvement in channel estimation MSE and less computing time compared to the conventional compressed channel estimation techniques.

8404-10, Session 2

Partial spread OFDM

A. A. Elghariani, M. D. Zoltowski, Purdue Univ. (United States)

Conventional OFDM performance deteriorates severely in the presence of channel frequency nulls at subcarrier frequencies. One way to improve frequency diversity of OFDM is to use linear precoders (spreading) which have been extensively studied in the literature. It is based on spreading data symbols across all the sub-carriers prior to modulation such that each carrier contains a linear combination of all the data symbols. Thus, if several carriers are lost due to spectral null, it may still be possible to retrieve all the transmitted symbols.

The fully loaded OFDM (or Full spread OFDM) has been extensively studied in the literature and several proposals have been introduced for the design of spreading matrix, but not much work has devoted to exploit the partially spread symbols over OFDM carriers.

In this paper we investigate more the advantages and disadvantages of this type of spreading considering its detection performance and receiver complexity with optimal and sub optimal techniques.

The objective of this paper is to analyze the performance of partially spread OFDM system based on optimal detection techniques such as ML and sub-optimum techniques such as MMSE. The extensive simulation has been implemented and an interesting results show that sub-optimal detection of partially spread OFDM could outperform optimal detection of fully spread OFDM in terms of Bit Error Rate (BER) and receiver complexity at certain spreading rates. These attractive results appear to be important especially in application where the high detestability and low complexity is more important than data rate.

The simulation is done with MATLAB, with 64 OFDM carriers, grouped into 16 subgroups. The reason for that is to make simulation of ML faster.The spreading matrix used in this simulation is the algebraically constructed Vandermonde matrix that has a better performance (as shown in the literature) over most of the available spreading matrices. The input symbols are chosen from the constellation of 4-QAM (QPSK) and 16-QAM and their number is chosen to get spreading rate of (1), (3/4) and (1/2).

8404-11, Session 2

Comparing the performance of continuous phase modulation and constant envelope orthogonal frequency division multiplexing

J. W. Nieto, Harris Corp. (United States)

This paper will compare the bit error rate performance of various CPM and CE-OFDM waveforms on AWGN and multipath/fading channels.

8404-12, Session 3

New method for numerical approximations of vector derivatives based on digital signal processing techniques

H. Brice, M. Z. Ahmed, Univ. of Plymouth (United Kingdom)

Accurate propagation models are required for predicting the propagation of electromagnetic waves within complex environments. This paper proposes the use of a new method to accurately compute the divergence and curl of electromagnetic fields. The computation of the derivatives of vector fields is normally approximated using numerical methods such as the Finite-Difference Time-Domain Method (FDTD), the Finite Integration Technique and the Multi-Resolution Time-Domain Method. These methods are all limited in terms of their accuracy, resolution, computational efficiency and numerical stability.

This paper introduces a new method for computing derivatives based on Two-Dimensional (2D) Digital Signal Processing (DSP) techniques. The method involves computing a numerical approximation of the derivative of a function by considering the frequency domain definition of the derivative and designing a 2D finite impulse response (FIR) filter that implements the differentiation. Appropriate windowing functions are used to ensure that the FIR response is as close to the ideal 2D differentiator response as possible.

This paper provides an example where the curl of a vector field is determined using this method and accuracy within a few percent is achieved.

The proposed innovative method can be extended to three dimensions and used to find numerical solutions of Maxwell's Equations, thus allowing it to be applied to the design of accurate propagation models.

8404-14, Session 3

A novel approach for using polyphase filter bank in directly digital rf conversion from rf to baseband

D. Zhang, Q. Jiang, M. Ahmed, HRL Labs., LLC (United States)

Digital filter bank techniques, especially polyphase filter bank, are key techniques in UWB receivers for digital complex conversion process to move analog to digital conversion (ADC) from baseband to IF. Currently, the dynamic range and conversion speed of the ADCs are the limiting factors in the applications of these filter-bank based receivers. In this paper, we propose a new approach to construct a filter-bank based receiver by integrating ADC with a polyphase filter bank. ADC consists of two building blocks, sample and hold unit (SH) and quantizer unit. By separating these two functional units of ADC, and integrating the quantizer unit into the subbands of a polyphase filter bank, we can have the sampling and hold unit working at a sampling frequency of fs and the quantizer unit working at a much smaller sampling frequency of fs/M (M is the decimation factor) in the subband; as a result, the ADC-polyphase filter bank can provide the function of direct digital RF down conversion. By using this technique, both analog IF converter and RF converter can be replaced by the ADC-polyphase filter bank. Therefore, all digital down conversion can be achieved in UWB receiver from RF to baseband. By this design, the UWB receiver structure and circuitry will be much simpler, IQ imbalance issue will be fully resolved, DSP will be much closer to antennas, and power efficiency will be improved significantly. In order to evaluate the effectiveness of the ADC-polyphase filter-bank, we conducted the MATLAB simulations for comparing the new design to a conventional system that uses a conventional ADC followed by a polyphase filter bank at the sample frequency (fs) of 1 GHz. Our simulation results showed that the ADC-polyphse filter bank provides almost the same functions as those in the conventional system. We also conducted the MATLAB simulation to demonstrate the advantages of this ADC-polyphase filter bank for signals with 64 GHz sampling frequency. The result of this simulation clearly demonstrated that, by using this novel approach, the ADC-polyphase filter bank can be directly applied as digital RF down conversion to replace analog converter from RF to baseband in the UWB receivers.

8404-15, Session 3

Serial concatenation schemes for PSK waveforms vs. turbo codes

F. C. Kellerman, Harris Corp. (United States)

This paper will compare the block and bit error rate performance of several modern iterative channel capacity approaching error correction schemes. Bit Interleaved Coded Modulation Iterative Detection (BICM-ID), Differential Phase Shift Key (DPSK) concatenated with Convolutional codes, Coherent PSK with Convolutional Codes will all be compared to the benchmark turbo codes.

8404-16, Session 4

Quadriphase DS-CDMA wireless communication systems employing the generalized detector with pulse shaping

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

Probability of bit-error performance of asynchronous direct-sequence code-division multiple-access (DS-CDMA) wireless communication systems employing the generalized detector (GD) constructed based on the generalized approach to signal processing in noise is analyzed. The effects of pulse shaping, quadriphase or direct sequence quadriphase shift keying (DS-QPSK) spreading, aperiodic spreading sequences are considered in DS-CDMA wireless communication systems based on GD and compared with coherent correlator or, equivalently, the matched filter (MF) receiver. An exact probability of bit-error expression and several approximations; one using the characteristic function (CF) method, a simplified expression for the improved Gaussian approximation (IGA) and the simplified improved Gaussian approximation (SIGA) are derived. Two main results are presented. Under conditions typically satisfied in practice and even with a small number of interferers, the standard Gaussian approximation (SGA) for the multiple-access interference component of the GD statistic and GD probability of bit-error performance is shown to be accurate. Moreover, the IGA is shown to reduce to the SGA for pulses with zero excess bandwidth. Second, the GD probability of bit-error performance of quadriphase DS-CDMA is shown to be superior to that of biphase DS-CDMA. Numerical examples with Monte Carlo simulation are presented to illustrate the GD probability of bit-error performance for square-root raised-cosine (Sqrt-RC) pulses and spreading factors of moderate to large values.

8404-17, Session 4

Joint optimization of source beamformer and relay coefficients using MSE criterion

B. K. Chalise, Y. D. Zhang, M. G. Amin, Villanova Univ. (United States)

Cooperative communications have emerged as a promising technique for enhancing link quality and coverage area in wireless networks. In this paper, we consider a cooperative network that employs multiple single-antenna distributed relays to assist the communications between a multi-antenna source node and a multi-antenna destination node using the simple amplify-and-forward protocol. The full potential of such network is realized if the linear processing at the source, destination and relay nodes is jointly optimized. Our objective is to minimize the mean-square error (MSE) under source and relay sum-power constraints, provided that the global channel state information is perfectly known. For the given source beamformer and relay coefficients, the optimal destination receiver turns to be a minimum MSE (MMSE) receiver. This MMSE receiver results in a nonconvex joint optimization problem having the source beamformer and relay coefficients as optimization variables. We propose two approaches to solve this problem. The first one is an iterative alternating technique where the source beamformer and relay coefficients are optimized one at a time while fixing the other, and the second approach is a non-iterative method where the relay coefficients are optimized for the given source beamformer which is chosen as the maximum-ratio-transmitter (MRT) for the source-relay channels. It is shown that both approaches can be reformulated as rank-one semidefinite relaxation (SDR) problems. From the solutions of these SDR problems, the best approximate rank-one solutions are obtained. The optimality of MRT is proven analytically under some conditions. Numerical results show superiority of the proposed methods. The iterative method yields equal or slightly improved performance compared to the non-iterative method.

8404-18, Session 4

Performance of partially coherent CPM on multipath fading channel

J. A. Norris, Harris Corp. (United States)

Constant Envelope, Continuous Phase Modulation (CPM) is highly desirable for low-power, battery-operated systems as well as for small-profile vehicular and aircraft systems where large amplifiers won't fit. In the past, CPM was noted for increased demodulator complexity (over simple PSK or FSK receivers) but with modern computational power it is possible to continue to improve the power efficiency of CPM modulation at the receiver. In the specific case of multipath, there are several known methods (Rake Receiver is one example) to resolve and correct for inter-symbol interference and phase distortion. This paper develops a standard CPM demodulation and compares the optimal coherent performance with a partially coherent receiver. Several methods are developed to compensate and correct for ISI due to multipath and the power efficiency is compared to the original, coherent demodulation.

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8405-01, Session 1

Defining and utilizing open architecture levels

M. Cramer, U.S. Navy (United States); J. R. Stack, Office of Naval Research (United States); B. Cordes, Naval Surface Warfare Ctr. Panama City Div. (United States)

No abstract available

8405-02, Session 1

Models and algorithms for determining inter-unit network demand

J. Ridder, S. Brett, Evidence Based Research, Inc. (United States); C. Burris, J. McEver, J. O'Donnel, The Johns Hopkins Univ. Applied Physics Lab. (United States); D. Signori, Evidence Based Research, Inc. (United States); H. Schoenborn, U.S. Dept. of Defense (United States)

Inter-unit demand for communication services is often used by analysts as the basis for assessing network performance and the impact on mission effectiveness. Traditional methods base inter-unit demand on Information Exchange Requirements (IER's) most often derived from a variety of disparate sources that can result in significant limitations. This paper describes modeling approaches and an algorithm that enables automated support for challenging steps in the tailoring of data from an established unit demand database in order to derive the inter-unit demand for specific scenarios. Such a capability is referred to as "demand parsing". The necessary operational constraints are modeled by applying an organizational distance metric, and weights associated with a small set of functionally driven usage patterns, to a node-link structure established at a level of resolution appropriate for the analytical context. An innovative agent based algorithm was then developed to address the resulting multi-objective optimization problem by calculating solutions that satisfy both the operational constraints and those imposed by the unit demand. Using an agent based modeling tool, the operational model and the algorithm were combined into a prototype tool that was applied within the parsing process to estimate the inter-unit demand for communications supporting units for a selected air operation. The errors in meeting both types of constraints were found to be less than or equal to 7% average and 15% peak, levels within the bound set for the errors in the unit demand database intended for first order assessments.

8405-03, Session 1

A flexible tool for scenario analysis of network demand

J. O'Donnel, The Johns Hopkins Univ. Applied Physics Lab. (United States); A. George, D. Wynn, S. Brett, J. Ridder, D. Signori, Evidence Based Research, Inc. (United States); H. Schoenborn, U.S. Dept. of Defense (United States)

This is another in a sequence of papers reporting on the development of innovative methods and tools for estimating requirements (demand) for net-centric capabilities and assessing network capabilities (supply). An extension of the demand estimation methodology, this paper focuses on steps required to better assess the adequacy of performance of candidate networks by means of an integrated tool. The steps include mapping units in a scenario to units in the associated database to determine their aggregate demand, developing an appropriate logical network with computational constraints dictated by the scenario and calculating inter-unit demand of the units in the logical network. Because of the complexity of the end-to-end process, assuring repeatability while facilitating rapid exploration of issues was a challenge. Early work in this area involved an analyst intensive process and incorporating small changes in the scenario was found to be not only time consuming but also error prone. To address this challenge component tools were evolved into an integrated capability with a user friendly interface. This allowed complete flexibility in manipulating data and rapidly computing inter-unit demand tailored to specific scenarios. Here the application of this integrated tool is used to illustrate a repeatable and flexible parsing capability.

8405-04, Session 1

The ozone widget framework: towards modularity of C2 human interfaces

D. B. Hellar, L. Vega, Next Century Corp. (United States)

The Ozone Widget Framework (OWF) is a common webtop environment for dynamic analytic workflows. In OWF lightweight web applications are distributed across the enterprise. These web applications, referred to as widgets, can be hosted on any server, domain, or technology platform in the enterprise. A key mission driver for OWF is to enable rapid capability delivery by lowering time-to-market with lightweight components. OWF has been deployed in a variety of C2 net centric contexts ranging from real-time analytics, cyber-situational awareness, to strategic and operational planning.

OWF is a Government Open Source Software (GOSS) effort, meaning source level access is available for free to all valid government organizations. As a GOSS product, the core development of OWF is directed by an inter-agency advisory board that prioritizes new features based on government mission needs. GOSS also implies that contributions from the greater government community are encouraged and integrated into the base package.

This paper discusses the future evolution of OWF to meet the demands of advanced net-centric operational needs:

1. Enhancing the core technology platform for increased scalable robustness and improved accessibility support

2. Growing the capability set of discoverable widgets through an integrated Ozone Marketplace solution

3. Empowering user-driven analytics for workflow assembly.

Together, OWF is moving towards the rapid delivery of modular human interfaces supporting modern and future command and control contexts.

8405-05, Session 1

Military clouds: utilization of cloud computing systems at the battlefield

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Cloud computing is known as a novel information technology (IT) concept, which involves facilitated and rapid access to networks, servers, data saving media, applications and services via internet with minimum hardware requirements. Use of information systems and technologies at the battlefield is not new. Information superiority is a force multiplier and is crucial to mission success. Recent advances in information systems and technologies provide new means to decision makers and users in order to gain information superiority. These developments in information technologies lead to a new term which is known as network centric capability. Similar to network centric capable systems, cloud computing systems are operational today. In the near future extensive use of military clouds at the battlefield is predicted. Integrating cloud computing

logic to network centric applications may increase the flexibility, cost-effectiveness, efficiency and accessibility of network-centric capabilities.

In this paper, cloud computing and network centric capability concepts are defined. Some commercial cloud computing products and applications are mentioned. Network centric capable applications are covered. Cloud computing supported battlefield applications are analyzed. The effects of cloud computing systems on network centric capability and on the information domain in future warfare are discussed. Battlefield opportunities and novelties which might be introduced to network centric capability by cloud computing systems are researched. The role of military clouds in future warfare is proposed in this paper.

It was concluded that military clouds will be indispensible components of the future battlefield. Military clouds have the potential of improving network centric capabilities, increasing situational awareness at the battlefield and facilitating the settlement of information superiority.

8405-06, Session 1

Overcoming the challenges of secure mobile applications for network-centric, data-sensitive applications

B. S. Farroha, D. L. Farroha, U.S. Dept. of Defense (United States)

Gaining the competitive advantage in today's aggressive environment requires our corporate leaders and Warfighters alike to be armed with up-to-date knowledge related to friendly and opposing forces. This knowledge has to be delivered between the core enterprise and tactical/mobile units at the edge. The type and sensitivity of data delivered will vary depending on users, threat level and current rules of dissemination. This paper will describe the Dynamic Digital Policy Management that depends on a solid identity, authenticating the user and the edge device. Next, Access Management is granted on a fine grain basis where each data element is classified with meta-data that is crypto-bound to the data itself to ensure authenticity of contents.

Providing capabilities is the number one objective of such systems; however, security cannot be ignored to defend this environment. Protecting user identity, protecting contents and limiting latency can be better achieved when the security requirements are considered at the inception phase of the system lifecycle. We are exploring new approaches of tunneling data and Key Management to ensure communication efficiency over limited physical resources. We are also analyzing methods of layering security to ensure delivery of critical data to intended destinations. The overall systems architecture assumes a mobile device that supports both a 3G/4G and a WiFi environment and would automatically select the best method of communication based on pre-determined criteria. The DoD and other federal agencies are working together with industry to ensure our next generation systems will meet the ever changing threats, deliver reliable, secure and affordable computing and communications environment. This paper will illustrate the required pre-conditions and the minimum security elements on the mobile edge to guarantee a trusted environment.

8405-07, Session 1

Securing services in the cloud: an investigation of the threats and the mitigations

B. S. Farroha, D. L. Farroha, U.S. Dept. of Defense (United States)

The stakeholder's security concerns over data in the clouds (Voice, Video and Text) are a real concern to DoD, the IC and private sector. This is primarily due to the lack of physical isolation of data when migrating to shared infrastructure platforms. The security concerns are related to privacy and regulatory compliance required in many industries (healthcare, financial, law enforcement, DoD, etc) and the corporate knowledge databases. The new paradigm depends on the service provider to ensure that the customer's information is continuously monitored and is kept available, secure, access controlled and isolated from potential adversaries.

Securing data in the clouds means many things to the stakeholders depending on their applications. Traditionally, Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) were the ways we implemented clouds. This limited view persists today with many organizations; however, the cloud platforms are being used in Storage, Computing as well as pioneering new ways of efficient voice, data and video communications. Gartner defines cloud computing as a style of computing where massively scalable IT-related capabilities are provided "as a service" using Internet technologies to multiple external customers.[1] This paper will be analyzing the many vulnerabilities and mitigations that are incurred when voice, video and data are kept in a secure cloud deployment. Several proven methods exist including VPNs and dedicated pipes/tunnels between the cloud and end systems. One of the most important concepts in the new clouds is that moving to a hosted communications solution doesn't mean you have to give up control; instead you need to negotiate a level of access with the provider to meet overall security and control over these services.

8405-08, Session 1

A framework for developing reliable corporate services in an agile environment

B. S. Farroha, D. L. Farroha, U.S. Dept. of Defense (United States)

DoD represents an environment of continuously changing mission requirements that requires our Information Systems to dynamically adapt to new needs and threats to deliver new capabilities, quicker, in a more efficient manner. Flexibility in design and Agility in development is the only way we will be able to keep up with these rapid changes. There are subtleties that must be considered as we adopt various agile methods: security, protection, control and authentication are all elements needed to posture our Information Technology systems to neutralize the real and perceived threats in today's unstable environment. Many systems are being tasked to ingest process and analyze dramatically different, high volume data sets than they were originally designed for and they have to interact with multiple new systems that were unaccounted for at design time.

Leveraging the tenets of security, we have devised a new framework that takes agility into a new realm to allow product development and deployment in a service-based or Cloud environment using agile development and deployment processes. Even though these criteria promise to hone the development effort, they actually contradict each other in philosophy where Services require stable interfaces, while Agile focuses on being flexible and change tolerant up to much later stages of development. This framework is focused on enabling a successful product development that capitalizes on both philosophies. The framework has been exercised in developing multiple capabilities to enable the Warfighter to utilize new and legacy backbone services to access in real-time information from edge networks.

8405-09, Session 1

Modeling socio-cultural processes in network centric environments

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The major focus in the field of modeling & simulation for Network Centric

environments has been on the physical layer while making simplifications for the human-in-the-loop. However, the human element has a big impact on the capabilities of Network Centric systems. Taking into account the socio-behavioral aspects of processes such as team building, group decision-making, etc. are critical to realistically modeling and analyzing system performance. Modeling socio-cultural processes is a challenge because of the complexity of the networks, dynamism in the physical and social layers, feedback loops and uncertainty in modeling data. We propose an overarching framework to represent, model and analyze various socio-cultural processes in Network Centric environments. The key innovation in our methodology is to simultaneously model the dynamism in both the physical and social layers while providing functional mappings between them.

8405-10, Session 2

Protection without detection: embracing a resilient coexistence in a malicious network environment

P. Ratazzi, Air Force Research Lab. (United States); J. S. White, Everis, Inc. (United States) and Clarkson Univ. (United States); J. R. McCoy, Everis, Inc. (United States)

Networking systems and individual applications have traditionally been defended using signature based tools to protect the perimeter sometimes at the cost of service, performance and information flow. These tools require knowledge of both the system on which they run, and the attack/threat of which they are preventing. It is now apparent that such practices only account for what we know to be malicious and hence the unknown is a “Zero Day Threat” when triggered as defences have yet to be “immunized” via the signature or other identifier of the now identified threat. In environments where the mission is paramount, critical information must be available through the network without the risk of endangering the enterprise or losing the salient information intent even when facing zero day threats. In this paper we discuss an approach to the Mission Assurance need to balance protection and availability. This technique is deemed “Protection without Detection” and deals specifically with network protection without sacrificing information availability. For availability to be met we must insure that our defences do not prevent information flow, that zero day unknowns are mitigated and Fight Through tactics are 100% within our control. Hence, we take a more proactive role, ensuring that we can operate at least in a reduced capacity if not at full during a small or large attack. The method presented herein assumes that all traffic is malicious without exception. In real time we analyse the data stream passing through an in-line device, recognize mission critical files, and apply trusted templates (as defined by our mission) to these files as they pass to the intended client. The end result of our initial work is a system which removes the threat of malicious data from the containers that wrap standard file types. In some cases this method sacrifices features that might be inherent in these files such as embedded forms but as we show in this paper this does not affect the critical data. We also discuss future application of the method that broadens the current work past file types to include protocols, meta data and authentication schemes.

8405-11, Session 2

Dynamic routing control in heterogeneous tactical networks with multiple traffic priorities

M. A. Fecko, L. Wong, J. Kang, T. Chen, V. Kaul, S. Samtani, Telcordia Technologies, Inc. (United States)

To efficiently use alternate paths during periods of congestion, we have devised prioritized Dynamic Routing Control Agent (pDRCA) that (1) selects best links to meet the bandwidth and delay requirements of traffic, (2) provides load-balancing and traffic prioritization when multiple topologies are available, and (3) handles changes in link quality and traffic demand, and link outages. pDRCA influences link selection by configuring the cost metrics on a router’s interface, which does not require any changes to the routing protocol itself. It supports service differentiation of multiple traffic priorities by providing more network resources to the highest priority flows. pDRCA does so by solving an optimization problem to find optimal links weights that increase throughput and decrease E2E delay; avoid congested, low quality, and long delay links; and exploit path diversity in the network. These optimal link weights are sent to the local agents to be configured on individual routers per traffic priority. Currently, pDRCA is integrated with an open-source software router and priority queues on Linux as a component of Open Tactical Router (OTR), which is being developed by ONR Dynamic Tactical Communications Networks (DTCN) program. In the recent experiments, SATCOM OPNET model was used to change its coding rate and hence link bandwidth in response to link fading. Upon retrieving dynamic bandwidth reports via a PPPoE interface, pDRCA was able to reroute traffic and improve mixed UDP/TCP throughput of high priority flows by 57-120% and reduce end-to-end delay by 39-59%.

8405-12, Session 2

Proactive and adaptive reconfiguration for reliable communication in tactical networks

H. Zeng, K. J. Kwak, J. Deng, Intelligent Automation, Inc. (United States); B. Fu, Y. Xiao, The Univ. of Alabama (United States); J. J. Jeski, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States)

Due to the layer-independency design, in current wireless networks, only after a complete failure occurs in one of the involved layers, is the next higher layer notified, and by then performance degradation may already be observed. Also, the new connection establishment process has to go through all the layers. It is time-consuming and usually results in an extra latency and resource unavailability within the transition region, which in turn leads to inefficient bandwidth usage and a poor user experience. Moreover, the root-cause of the connection termination is typically hidden, and not utilized for the repair or reestablishment. To mitigate the problem, in this paper, we propose a proactive and adaptive cross-layer reconfiguration (PACR) scheme for reliable communication in tactical networks. The PACR scheme allows the user (e.g., network operator) to adaptively reconfigure operating parameters in the corresponding layers through proactive prediction, root-cause identification, and cross-layer negotiations. The core of the PACR scheme is an integrated cross-layer information sharing architecture that expedites information exchange and inter-layer interactions between different network layers in a proactive manner. Through simulation and experiments, it has been shown that our proposed PACR scheme can significantly improve the network performance, and facilitate the nodes or users to make smart decisions accordingly in an adaptive manner.

8405-13, Session 2

Addressing security, collaboration, and usability with tactical edge mobile devices and strategic cloud-based systems

C. J. Graham, Raytheon Co. (United States)

Success in the future battle space is increasingly dependent on rapid access to the right information. Faced with a shrinking budget, the Government has a mandate to improve intelligence productivity, quality, and reliability. To achieve increased ISR effectiveness, leverage of tactical edge mobile devices via integration with strategic cloud-based infrastructure is the single, most likely candidate area for dramatic near-term impact. This paper discusses security, collaboration, and usability components of this evolving space. These three paramount tenets embody how mission information is exchanged securely, efficiently, with social media cooperativeness.

Tenet 1: Complete security, privacy, and data integrity, must be ensured

within the net-centric battle space. This paper discusses data security on a mobile device, data at rest on a cloud-based system, authorization and access control, and securing data transport between entities.

Tenet 2: Lack of collaborative information sharing and content reliability jeopardizes mission objectives and limits the end user capability. This paper discusses cooperative pairing of mobile devices and cloud systems, enabling social media style interaction via tagging, meta-data refinement, and sharing of pertinent data.

Tenet 3: Fielded mobile solutions must address usability and complexity. Simplicity is a powerful paradigm on mobile platforms, where complex applications are not utilized, and simple, yet powerful, applications flourish. This paper discusses strategies for ensuring mobile applications are streamlined and usable at the tactical edge through focused features sets, leveraging the power of the back-end cloud, minimization of differing HMI concepts, and directed end-user feedback.

8405-14, Session 2

A decision and utility theory construct for dynamic spectrum access systems

T. Martin, K. Chang, George Mason Univ. (United States)

Dynamic Spectrum Access (DSA) networks seek to opportunistically utilize unused RF capacity rather than relying on static spectrum assignments. The networks change their spectrum access characteristics such as frequency, power, and modulation to adapt and allow for access to spectrum while not causing harmful interference to other spectrum users. An essential element of DSA system operation is decision-making under uncertainty due to incomplete or inaccurate situational awareness.

This paper describes ongoing efforts in applying decision and utility theory constructs to DSA systems. The construct combines elements of communications theory, formal value and utility axioms of probability and decision theory, and constraint satisfaction. It provides a mechanism that allows DSA systems to quantitatively evaluate options for attaining the desired capacity subject to constraints in radio performance, uncertainty in spectrum dynamics, operating cost, and avoidance of harmful interference to other spectrum users. The resulting construct provides insight into DSA operational trades for evaluating, ranking, and selecting alternative solutions. A decision-theoretic construct is developed and analyzed to illustrate the methodology and resulting trades among alternative utility function classes.

8405-15, Session 2

Information dissemination in disadvantaged wireless communications using a data dissemination service and content data network

M. Gillen, J. P. Loyall, K. Zita Haigh, R. Walsh, C. Partridge, BBN Technologies (United States)

Disadvantaged wireless communications, such as those in fractionated spacecraft systems, need real-time, reliable, and fault tolerant information dissemination from information producers (such as sensors) to information consumers (such as information exploitation, analysis, or command and control systems). Such systems are well suited to the publish-subscribe paradigm, but cannot afford the large footprint of many pub-sub systems and do not provide the underlying high-bandwidth, stable connectivity many pub-sub systems assume. Similarly, pub-sub systems cannot, by themselves, provide the real-time performance and quality of service needed by many mission-critical and spacecraft applications; they need enforcement and control provided by an underlying network.

This paper presents a concept for a dissemination system suited to space-borne platforms that combines a lightweight implementation of the OMG's Data Dissemination Service with a simplified Content Delivery Network. The result is a topic-based pub-sub information dissemination service that supports decoupled publishers and subscribers of varying numbers, automated failover, and quality of service (QoS), coupled with a topic-based network that can enforce QoS parameters and efficiently deliver published messages based on the subscriptions registered by consumers.

8405-16, Session 4

DARPA's HARDI program for a wide field of view, VIS-NIR-SWIR detector based on a curved focal plane array

D. K. Shenoy, Defense Advanced Research Projects Agency (United States)

No abstract available

8405-17, Session 4

Advanced thermal management technologies for defense electronics

A. Bar-Cohen, Univ. of Maryland, College Park (United States); K. Bloschock, System Planning Corp. (United States)

Thermal management technology plays a key role in the continuing miniaturization, performance improvements, and higher reliability of electronic systems. For the past decade, and particularly, the past 4 years, DARPA has aggressively pursued the application of micro- and nano-technology to reduce or remove thermal constraints on the performance of defense electronic systems. The DARPA Thermal Management Technologies (TMT) portfolio is comprised of five technical thrust areas: Thermal Ground Plane (TGP), Microtechnologies for Air-Cooled Exchangers (MACE), NanoThermal Interfaces (NTI), Active Cooling Modules (ACM), and Near Junction Thermal Transport (NJTT). An overview of the TMT program will be presented with emphasis on the goals and status of these efforts relative to the current State-of-the-Art. The presentation will close with future challenges and opportunities in the thermal management of defense electronics.

8405-18, Session 5

Wide area, persistent surveillance video with no gimbal

G. Egnal, Argusight, Inc. (United States)

Modern aerial video has depended on high quality gimbals. The benefits of these gimbals include motion correction, navigational information, and a standardized mounting interface for sensors to the platform. The downside to the gimbal is the weight, power, and cost of the system, as well as the potential for mechanical failure. These negative factors matter more and more as medium sized and small unmanned aircraft proliferate. Luckily, in many cases, it is possible to fly without a gimbal. With the advent of large format video systems, we can achieve high quality video in the visible domain with un-gimbaled video. The massive field of view and high resolution given by these new systems provides a large amount of data redundancy, and it is possible to use this redundancy to improve algorithmic stabilization, to overcome aircraft motion, and to sharpen geolocation estimates. We describe an example system that flies without a gimbal and detail the algorithms that facilitate the high quality of the video. We present actual imagery from a system with no gimbal with relevant data to evaluate its performance, and we discuss the tradeoffs involved in system design with and without a gimbal.

8405-19, Session 5

LEAPS and WFPAC status

A. S. Moore, G. Hazel, B. Schulz, Logos Technologies, Inc. (United States)

The Lightweight Expeditionary Airborne Persistent Surveillance (LEAPS) system is a compact, WAAS system designed to be carried by small UAV's such as the RQ-7 Shadow. In its nominal CONOPS, it supports vehicle and dismount detection and tracking in a persistent circle of approximately 4 km radius. It supplies motion imagery in real time at greater than 5 Hz frame rate to up to 10 users through a TCDL data link. It can store imagery for up to 5 hours for access in flight or after landing. It is being integrated into the WFPAC operational demonstration and scheduled for a field user evaluation in early 2012.

8405-20, Session 5

Kestrel aerostat-based wide area persistent surveillance

D. R. Luber, Logos Technologies, Inc. (United States)

Kestrel is an aerostat-based, day/night wide-area persistent surveillance sensor system being deployed for protection of forward operating bases in Afghanistan. Executed by the Army G2 under a NAVAIR contract, Logos Technologies, Inc. (Logos) has developed and delivered the first systems in less than one year. The system provides real-time and forensic data over 100 km2 at resolutions making it possible to detect and track dismounts. The system provides real-time tracking and storage to provide full forensic analysis.

8406-02, Session 1

Neuro-fuzzy prediction method for corrupted fingerprint restoration

S. Bakhtiari, E. Mohyeddinbonab, S. S. Agaian, M. Jamshidi, The Univ. of Texas at San Antonio (United States)

In this paper, we present a new fingerprint reconstruction method based on a Neuro-Fuzzy prediction approach. Most of the fingerprint images suffer from low quality in terms of discontinuous edges or hardly observable minutiae. The role of these two features is highly critical in recognition missions. Therefore, if they are not clearly exposed in fingerprint images, the recognition system will fail to make correct decisions. However, a preprocessing step can significantly help to produce more reliable recognition outputs. In the proposed preprocessing method of this paper, the network is first fed by a number of corrupted and high quality fingerprint images, in the training phase. After being trained, the network is tested by corrupted images. The experimental results have shown that the new approach is able to connect the regions that are part of an edge to generate continuous edges as well as enhancing the minutiae. The decisions made by this system are more reliable compared to the system which does not apply the preprocessing method.

8406-03, Session 1

Parallel computing-based sclera recognition for human identification

Y. Lin, Xidian Univ. (China); E. Y. Du, Z. Zhou, Indiana Univ.-Purdue Univ. Indianapolis (United States)

The sclera is white and fibrous tissue that covers the entire eyeball except the cornea. The blood vessel in sclera can be imaged under visible wavelength and the structures of these vessels are unique and stable during one's life. Compared to iris recognition, sclera recognition can achieve higher recognition accuracy under visible wavelength. Because of the heavy computation in matching step, sclera recognition is a time-consuming process. This limits application of sclera recognition in many situations. In this paper, we propose a GPU-base parallel computing sclera recognition approach to exploit Single Instruction Multiple Data (SIMD) architecture. The experiment results show the proposed method executed on general purpose graphic process unit (GPGPU) can dramatically improve the matching speed in hundreds of times.

8406-04, Session 1

SURF characterized limited physiological information for face recognition

D. R. Kisku, Asansol Engineering College (India); A. Rattani, Univ. degli Studi di Cagliari (Italy); P. Gupta, Indian Institute of Technology Kanpur (India); J. K. Sing, Jadavpur Univ. (India)

Face recognition can be considered as one of the most dynamic and complex research areas in machine vision and pattern recognition due to the variable appearance of face images. Changes in appearance may occur due to many factors, such as facial attributes compatibility complexity, the motion of face parts, facial expression, pose, illumination and partly occlusion. As a result face recognition problem become ill-posed.

This paper proposes a new local feature based face recognition technique which makes use of dynamic (mouth) and static (eyes, nose) salient features as limited physiological information of face obtained through SURF descriptor. SURF (Speeded up robust features) descriptor is a robust image descriptor. It can be used in computer vision tasks like object recognition or 3D reconstruction. It is known as the improved version of the SIFT (Scale Invariant Feature Transform) descriptor. The standard version of SURF is several times faster than SIFT and more robust against different image transformations than SIFT. The proposed work presents a robust and efficient face recognition system using SURF descriptor (Speeded up Robust Features) and limited physiological information of face. The proposed technique extracts performant scale and rotation invariant interest points from salient facial landmarks (eyes, mouth, nose) automatically from each face image. SURF descriptor is used to determine all facial keypoints from each landmark. These feature points obtained from each facial landmark are then fused by concatenation process into an augmented group feature vector. Further, the matcher reliability is increased by Doddington's user dependent matcher weighting scheme. The proposed technique has been tested against the three databases, namely, FERET, ORL, BANCA and IITK face databases. The experimental results exhibit robustness of the proposed face recognition system.

8406-05, Session 2

dLocAuth: a dynamic multifactor authentication scheme for mCommerce applications using independent location-based obfuscation

I. A. Lami, T. Kuseler, The Univ. of Buckingham (United Kingdom)

Multi-factor authentication enhances the security of remote authentication. However, currently only 30% of financial services are available to clients via mobile transactions due to weaknesses in existing authentication schemes. Majority of these schemes lack the time and location assurance of face to face office-based authentication scenarios, as well as being completely static. I.e. both the client and authenticator follow an "exact pre-agreed" order of steps to generate and validate the multi-factor authentication data. Therefore, any knowledge of the multi-factor sequence represents valuable information to an attacker on the authentication scheme. This paper proposes a scheme that will dynamically choose the steps of the multi-factor authentication process. Current time and GPS-based location of the client are used to generate a one-off sequence to obfuscate the steps on the mobile device. On the authenticator side, the client's location is then independently recovered from the cellular network serving that mobile device and used to de-obfuscate the authentication process. The dynamically changing order and number of the processing steps shall further enhance a secure and reliable authentication even if any or all of the employed authentication factors are compromised. Android based trials show the viability of this scheme for use in mobile device based authentications.

8406-06, Session 2

Comprehensive feature and texture fusion-based image registration approach

F. R. Bowen, E. Y. Du, Indiana Univ.-Purdue Univ. Indianapolis (United States); J. Hu, Purdue Univ. (United States)

With the development of mobile and web technologies, there exist a vast number of images of the same scenes or objects but taken from varying viewpoints and under differing lighting conditions available in the world wide web. With such a large set of mobile data, applications

seek to match images from multiple sources to provide important information about an event, object, scene, etc. Image registration is an essential step in object recognition. It aims to estimate the transformation parameters such that one image can be geometrically aligned with another. Existing methods seek to minimize some dissimilarity measure through optimization approaches such as the gradient descent method or particle swarm theory. The challenge associated with the optimization methods lies in the unintended convergence of local minima or maxima. Feature-based approaches attempt to identify keypoints of an image that are suitable for the homography estimation; however, these methods produce a large set of candidate points. We propose a comprehensive image registration method that takes advantage of feature point detection but imposes a strict method for identifying optimal interest points for the estimation of the homography matrix. The proposed method combines feature-based results with texture-based optimizations for the selection of control points. The preliminary experimental results show that our methodology can greatly reduce the computational time while improving registration accuracy.

8406-07, Session 2

Human visual system-based smoking event detection

A. Odetallah, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

Abstract- Human action (e.g. smoking, eating, and phoning) analysis is an important task in various application domains like video surveillance, video retrieval, human-computer interaction systems, and so on. Smoke detection is a crucial task in many video surveillance applications and could have a great impact to raise the level of safety of urban areas, public parks, airplanes, hospitals, schools and others. The detection task is challenging since there is no prior knowledge about the object's shape, texture and color. In addition, its visual features will change under different lighting and weather conditions.

This paper presents a system for detecting human smoking events in a sequence of images. In developed system, motion detection and background subtraction are combined with motion-region-saving and smoke-based image segmentation to filter out potential smoke regions which are further analyzed to decide on the presence of smoke. The developed method is capable of detecting the smoking events of uncertain actions with various cigarette sizes, colors, and shapes. Experimental results show the effectiveness and real-time performances of presented method in smoking event analysis.

8406-08, Session 2

Information encryption and retrieval in mid-RF range using acousto-optic chaos

M. R. Chatterjee, A. Kundur, Univ. of Dayton (United States)

Since 2008, the possibility of using chaos in a hybrid acousto-optic feedback loop to modulate, encrypt, transmit and recover information signals has been studied by Chatterjee and co-workers [1]. The feasibility, reliability and robustness of the system have been examined analytically and via simulations at relatively low frequencies (upto about 1 KHz). The onset of chaos and the dynamical characteristics of the chaotic carrier have recently been examined using both Lyapunov exponents and bifurcation maps [2]. It has been shown that applying a low-frequency ac signal in juxtaposition with the necessary dc bias voltage via the bias input of the RF oscillator driving the acoustic source of the acousto-optic setup leads to an encrypted first-order optical output that exhibits 5% to 10% tolerance to three systems parameters or "keys", viz., feedback delay, feedback gain, and the quiescent bias. Two different methods of message recovery have been proposed- (i) a heterodyne approach involving a matched Bragg cell at the receiver, and (ii) using a dual-Bragg cell receiver. In this paper, we extend the scope of this application to the mid-RF range (5 MHz or less), with the intent of including video and digital signals.

[1] M.R. Chatterjee and M. Al-Saedi, "Examination of chaotic signal encryption and recovery for secure communication using hybrid acousto-optic feedback", Opt. Eng. 50, 055002 (May 02, 2011).

[2] M.R. Chatterjee and M.A. Al-Saedi, "Chaotic bandgaps in hybrid acousto-optic feedback and their implications," SPIE Proceedings, vol. 8162, Free-Space and Atmospheric Laser Communications XI, Arun K. Majumdar; Christopher C. Davis, Editors, Aug. 2011.

8406-09, Session 3

Biometric templates selection and update using quality measures

A. J. Abboud, S. A. Jassim, The Univ. of Buckingham (United Kingdom)

To deal with severe variation in recording conditions, most biometric systems acquire multiple biometric samples, at the enrolment stage, for the same person and then extract their individual biometric feature vectors and store them in the gallery in the form of biometric template(s), labelled with the person's identity. The number of samples/templates and the choice of the most appropriate templates influence the performance of the system. The desired biometric template(s) selection technique must aim to control the run time and storage requirements while improving the recognition accuracy of the biometric system. This paper is devoted to elaborating on and discussing a new two stages approach for biometric template selection. This approach uses a quality-based clustering, followed by a special criterion for the selection of an ultimate set of biometric templates from the various clusters. Then the adaptive version of the same approach is developed to select adaptively a specific number of templates for each individual. The number of biometric templates depends mainly on the performance of each individual (i.e. gallery size should be optimized to meet the needs of each target individual). We will use biometric quality measures to update enrolled biometric templates after enrolment and also we can develop quality-based individual-based update schemes.

8406-10, Session 3

Multibiometrics fusion for identity verification

D. R. Kisku, Asansol Engineering College (India); A. Rattani, Univ. degli Studi di Cagliari (Italy); P. Gupta, Indian Institute of Technology Kanpur (India); J. K. Sing, Jadavpur Univ. (India)

Multimodal biometric system combines multiple evidences obtained from multiple biometric sources like face, palm print and fingerprint, multiple fingers of a user, multiple classifiers etc in order to verify the identity of an individual or identify the unknown suspicious individual. Information presented by multiple sources can be fused at different and distinct levels of fusion, including sensor level, feature extraction level, match score level and decision level. The reason to combine multiple biometric sources of information or combine multiple modalities is to improve the verification or identification performance and increase the efficiency of the overall Multibiometric system. The proposed work reports a feature level fusion of face, palmprint and fingerprint modalities using log polar mapping and fusion of SIFT features. Initially, the representations of face, palmprint and fingerprint images are done by log polar transform and further, from these log polar transform invariant SIFT features are extracted. Log polar transform maps the images from Cartesian plane to log polar plane. SIFT features are invariant to rotation, scaling and partial illumination. Due to this invariant characteristics, SIFT features are successfully applied to many object recognition problems. The SIFT points obtained from three biometrics modalities are then fused using 'concatenation' approach and a feature vector is formed. For identity verification, correlation metric is applied between two feature vectors obtained from the corresponding reference and query biometric samples. The proposed system has been tested and evaluated on IIT Kanpur multimodal database. Outcomes are very impressive and encouraging to demonstrate the state-of-the-art performance of the proposed Multibiometric system.

8406-11, Session 3

Adaptive error correction codes for face identification

W. R. Hussein, H. Sellahewa, S. A. Jassim, The Univ. of Buckingham (United Kingdom)

Face recognition in uncontrolled environments is greatly affected by fussiness of face feature vectors as a result of extreme variation in recording conditions (e.g. illumination, poses or expressions) at different sessions. Many techniques and classifiers have been developed to deal with these variations resulting in improved performances. This paper aims to model template fussiness as errors and investigate the use of error detection/correction techniques. Error correction codes (ECC) have recently been used for biometric key generation but not on biometric templates. We have investigated error patterns in binary face feature vectors extracted from different image windows of differing sizes and for different recording conditions. By estimating statistical parameters for the inter-class and intra-class distributions Hamming distances in each block, we encode with appropriate ECC's. We shall demonstrate that using different combinations of BCH-based ECC's for different blocks and different recording conditions result in different accuracy rates, and that using ECC's results in significantly improved performance. Performance is tested for binarised wavelet templates with and without ECC's using three face databases: Extended Yale-B; Yale; and ORL.

8406-12, Session 3

Real-time face identification method in mobile environments

D. Lee, S. Yeom, Y. Woo, S. Kim, Daegu Univ. (Korea, Republic of)

Face identification from a long distance is very challenging since captured images are often degraded by blurring and noise as well as low resolution of the image size. For real-time face identification, there are several issues to be considered such as the computational complexity and available storage of the mobile device, and network bandwidth in the mobile environments. This paper discusses a real-time face identification method with correlation-based filtering and sequential testing stages, and its implementation on the mobile device. The correlation-based filter is trained on the central server and necessary information is transmitted to the database of the mobile device. In the system based on the correlation-based filtering, both of the face detection and identification processes are performed simultaneously. Several categories of correlation-based filters are implemented and compared in term of the identification performance and computational load. The identification unit is built in the mobile device, which include the sequential testing stages comprising color and shape verification processes; the skin-color test and edge-mask filtering are employed to verify the candidate face regions. In the experiments and simulation, false acceptance and reject rates as well as time complexity are obtained to evaluate the system performance. It will be shown that the proposed system operates successfully to identify face at a distance in the mobile environments.

8406-13, Session 4

Arabic handwritten: pre-processing and segmentation

M. Maliki, S. A. Jassim, N. Al-Jawad, H. Sellahewa, The Univ. of Buckingham (United Kingdom)

Pre-processing and segmentation stages play a vital role in the performance of Optical Character Recognition (OCR) systems and handwritten/typed text recognition. This paper presents two algorithms. Instead of using the typical way of segmenting a document into lines, words, and then characters, using seed/fill strategy, the first proposed algorithm works on segmenting the whole document into sub-words. These sub-words could be segmented, if necessary, into characters. This algorithm is also designed to solve the problem of overlapping that occurs between words and sub-words. This results in reducing the time needed for segmentation and leads to improved character segmentation accuracy.

The second proposal is to improve the pre-processing stage for baseline estimation, slope correction, and slant removal. Linear regression is applied on sub-words to find average x-coordinates, y-coordinates and the part of sub-word that has high density. Then multi rotation procedure is performed on the sub-word to determine the best rotation angle.

This paper will demonstrate the benefits of these proposals by conducting extensive experiments on publicly available known and in-house created databases.

8406-14, Session 4

Saccadic eyes recognition using 3D shape data from a 3D near infrared sensor

S. Guo, Alcorn State Univ. (United States); J. Tang, Michigan Technological Univ. (United States); J. B. Parakkat, K. M. Robinette, Air Force Research Lab. (United States)

Saccadic eyes are important human behaviors and have important applications in commercial and security fields. In this paper, we focus on saccadic eyes recognition from 3-D shape data acquired from a 3-D near infrared sensor. Two salient features, normal vectors of meshes and curvatures of surfaces, are extracted. The distributions of normal vectors and curvatures are computed to represent eye states. The support vector machine (SVM) is applied to classify saccadic and non-saccadic eyes states. To verify the proposed method, we performed three groups of experiments using different strategies for samples selected from 300 3-D data, and present experimental results that demonstrate the effectiveness and robustness of the proposed algorithm.

8406-15, Session 4

Mathematical properties of a sensitivity measure for quantifying feature variation

S. P. DelMarco, BAE Systems (United States)

Feature extraction is a key component of typical pattern recognition algorithms. Usually performance of feature extractors is governed by several parameters. Characterizing parameter value effect on feature extraction performance is valuable for aiding in appropriate parameter value selection. Often, the parameter space is discretized and the effect of discrete parameter values on feature variation is analyzed. However, it can be problematic to determine a discretization density that contains suitable parameter values. To address this issue, this paper further explores a previously-introduced sensitivity measure for quantifying feature variation as a function of parameter space sampling density. Further mathematical properties of the sensitivity measure are determined. Closed form expressions for special feature set relationships are derived. We investigate sensitivity measure convergence properties as a function of increasing parameter space sampling density. We present conditions for sensitivity measure convergence, and provide closed form expressions for the limiting values. We discuss divergence and present an example in which the measure diverges. We show how sensitivity measure convergence can be used to choose an appropriate parameter space sampling density. Numerical examples of sensitivity measure convergence are presented for feature extraction on natural imagery.

8406-16, Session 4

Salient region detection for object tracking

C. Fan, M. Jiang, Wuhan Univ. of Science and Technology (China); J. Tang, Michigan Technological Univ. (United States)

This paper proposed an algorithm for salient region detection, which can be used in object detection ,tracking, security video monitoring and machine vision fields. Our algorithm extends Context-Aware Saliency algorithm, which extracted salience area from image by local low-level considerations, global considerations, visual organizational rules, and high-level factors.

Our algorithm evaluates similarity measurement between frames and uniqueness feature of the spatial area in salient regions to detect and extract moving objects from video frames. The proposed algorithm firstly computes the global similarity between the video frames to get similarity maps. And then finds the coarse position of the moving region in the similarity maps. Finally, gets moving objects by computing color similarity in multiple scales. The experimental results show that our method can effectively detect salient region and extract the moving object in static background in video frames.

8406-17, Session 4

New methods for high-capacity embedding in multimedia covers using redundant number systems with adjunctive numerical representations

J. C. Collins, The Univ. of Texas at San Antonio (United States)

By introducing the concept of combining redundant number systems with adjunctive numerical representations for multimedia bit planes, we will show a novel approach to improving the embedding capacity in various multimedia carrier files. The approach we describe involves several steps such as a judicious selection of a unique binary adjunctive number representation, followed by mapping this optimal representation into a redundant number scheme and then finally, using first and second order statistical estimators to select the most appropriate embedding algorithm. It will be shown that this new steganography method has minimal visual and auditory distortive affects while also exhibiting an improved statistical analysis profile making it less susceptible to various steganalysis attacks. This paper begins by reviewing the common numerical methods used in today's binary-based steganography algorithms. We then cover the concepts and challenges found when attempting to implement complex embedding algorithms using a series of redundant number systems. Finally, we introduce a class of adjunctive numerical systems that, when used in conjunction with various redundant number systems, provide the necessary domain and range mapping needed for our improved steganographic algorithms.

8406-18, Session 5

Privacy-aware access control for video data in intelligent surveillance systems

H. Vagts, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Surveillance systems become powerful. Objects can be identified and intelligent surveillance services can generate events when a specific situation occurs. Such surveillance services can be organized in a Service Oriented Architecture (SOA) to fulfill surveillance tasks for specific purposes. Therefore the services process information on a high level, e.g., just position of an object. Video data is still required to visualize a situation to an operator and is required as evidence in court. Processing of personal related and sensitive information threatens privacy. To protect the user and to be compliant with legal requirements it must be ensured that sensitive information can only be processed for a defined propose by specific users or services. This work proposes an architecture for Instance Oriented Access Control that enforces the separation of data between different surveillance tasks. Access controls are enforced at different levels: for the users starting the tasks, for the services within the tasks processing data stored in central store or calculated by other services and for sensor related services that extract information out of the raw data and provide them. Access to the raw video data is secured by an ontology-based approach, which allows a flexible and user-centric access. A video sequence is only stored, if a specific event occurs. Depending on the event, the users visible in the video can specify by themselves, which services or users can read or store a sequence. The proposed approaches have been implemented in a demonstrator system.

8406-19, Session 5

A fractal-based nonlocal means image denoising algorithm

S. C. Nercessian, K. A. Panetta, Tufts Univ. (United States); S. S. Agaian, The Univ. of Texas at San Antonio (United States)

Image denoising is one of the most studied problems in image processing. The aim of image denoising is to recover an image from its noisy observation. Most existing denoising algorithms tend to smooth textures and fine image details or structures. More recently, the non-local means (NLM) denoising algorithm was based on a set of assumptions which is different than other methods. Namely, it assumes that images naturally contain redundancy which can be leveraged for image denoising. Image denoising can consequently be achieved by averaging similar image templates which are found within the image. The resulting NLM image denoising algorithm has demonstrated state-of-the-art image denoising results. In this paper, a new fractal-based non-local means image denoising algorithm is proposed. The new algorithm is based on a more generalized assumption than the original non-local means denoising algorithm. Motivated by fractal coding, the proposed approach assumes that images contain a certain amount of redundancy at many different scales. Therefore, the proposed image denoising algorithm searches for similar image patches at different scales, and thus, it generates more relevant image templates for the denoising process. Moreover, the traditional NLM algorithm can be viewed as the specific instance of the proposed algorithm when image patches are found only on a single scale. Accordingly, experimental results illustrate the improved denoising results obtained by the proposed method.

8406-20, Session 5

Incremental fusion of partial biometric information

A. J. Abboud, S. A. Jassim, The Univ. of Buckingham (United Kingdom)

Existing face recognition schemes are mostly based on extracting biometric feature vectors either from whole face images, or from a fixed facial region (e.g., eyes, nose, and mouth). Extreme variation in quality conditions between biometric enrolment and verification stages badly affects the performance of face recognition systems. Such problems have partly motivated several investigations into the use of partial facial features for face recognition. Nevertheless, partial face recognition is potentially useful in several applications, for instance, it used in forensics for detectives to identify individuals after some accidents such as fire or explosion. In this paper, we propose a scheme to fuse the biometric information of partial face images incrementally based on their recognition accuracy (or discriminative power) ranks. Such fusion scheme uses the optimal ratio of full/partial face images in each different quality condition. We found that such scheme is also useful for full face images to enhance authentication accuracy significantly.Our experiments show that the required ratio of full/partial facial images to achieve optimal performance varies from (10%) to (70%) according to the quality conditions whereas the authentication accuracy improves significantly for low quality biometric samples.

8406-21, Session 5

Retinal image analysis for quantification of progression of ocular disease

S. Chakravarty, SGT, Inc. (United States); M. Acharyya, Advenio TecnoSys Pvt. Ltd. (India)

The study intends to develop a Computer Aided Automated Screening (CAAS) system for early detection of Diabetic and Hypertensive Retinopathy. This involves identification and quantitative description of the main diagnostic signs and patterns in retinal vasculature. The features taken into account are fractal dimension, vessel caliber (diameter, width), vessel tortuosity, generalized and focal vessel narrowing, presence of Gunn or Salus signs and artery to vein diameter ratio. Subsequently a global measure combining all these features is to be designed which would be able to quantify the progression of the disease. The aim of the research is to develop algorithms that would help with parameterization of the eye fundus images, thus improving the diagnostics.

Algorithm is developed on high resolution digital fundus images.

At first the vasculature is extracted separately by a novel vessel enhancement filter and multiscale analytical scheme based on non-subsampled contourlets. The filter combines the eigenvalues of the Hessian matrix, the response of matched filters, and edge constraints on multiple scales. The numerous vessel segments identified are to be linked to reconstruct a connected vessel network, where bifurcations and crossings are properly recognized. Vessel diameter measurements is obtained by fitting a 2D model, which resembles an idealized cross sectional profile running along the length of a vessel segment in a small region of interest. Gunn and Salus signs are detected by looking at changes in vessel caliber or vessel direction at crossings. A new tortuosity measure, able to reproduce the grading of this features as perceived by clinical experts, is worked on. A novel technique for classification of vessels into arteries and veins is proposed for arteriolar narrowing measure which is given by ratio of diameters of artery-to-vein (A/V ratio). Fractal dimension is computed in both monofractal and multifractal analysis.

Finally, a single global measure that can summarize the branching pattern of the retinal vasculature as a whole along with the above structural pattern measures of the vessel is found. Such a measure may combine subtle vascular abnormalities and thus be a more sensitive indicator of microvascular disease and proliferative retinopathy.

CAAS systems developed for analyzing retinal fundus images can assist in reducing the workload of ophthalmologists and improving the screening accuracy. Utilizing the computer and network technologies, these systems will allow medical institutions to perform screening of retinal images with the computer analysis as the first processing stage, and then trained specialists observe only those images designated as possibly abnormal or even the CAAS system itself can take the responsibility usually done by specialists. Specialists will be liberated from tedious labor work, the regional medical difference will be narrowed, the diagnosis accuracy will be improved, and then people's fundus photography examination chance will be increased.

8406-22, Session 5

Different analysis methods for forensic investigation of mobile devices using commercial tools: an overview

K. Kröger, R. Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of the paper is to show the usefulness of modern forensic software tools for forensic investigation of mobile devices.

In particular, we focus on the newest versions of available commercial tools, show how the relevant stored data is extracted and analyzed. Outlines are the differences between the commercial tools CELLEBRITE UFED Physical Pro, Oxygen Forensic Suite 2011, Paraben Device Seizure and XRY Forensics.

8406-23, Session 5

Improving energy efficiency in handheld biometric applications

D. C. Hoyle, J. W. Gale, R. K. Sanders, R. W. Ives, R. N. Rakvic, R. C. Schultz, U.S. Naval Academy (United States)

With improved smartphone and tablet technology, it is becoming increasingly feasible to implement powerful biometric recognition algorithms on portable devices. At the U.S. Naval Academy, an iris recognition algorithm known as Ridge Energy Direction (RED) has already been developed. This research will explore the implications of porting sections of this algorithm onto handheld devices. Currently, the algorithm uses floating point operations. If this algorithm could be converted to use integer operations it could drastically reduce the energy consumed by the processor. During initial research, integer additions consumed sixty-seven percent less energy than floating point additions. Similarly, integer multiplications consumed twenty-eight percent less energy than floating point multiplications. Considering the millions of operations required to filter a high resolution image, the savings in energy could be substantial. This research will attempt to discover how much energy can be saved from this conversion. In addition, the effect on the accuracy of the algorithm will be studied in order to quantify the tradeoff of energy vs. performance. In terms of hardware, the main platforms of interest are the Motorola Droid X2 and the Samsung Galaxy SII, both of which run the Android operating system and have native processors and cameras suited to perform iris recognition. As part of our future work, we plan to analyze these energy efficient changes in the context of an Apple-based handheld device, as well.

8406-24, Session 5

Local enhancement and denoising algorithms on arbitrary mesh surfaces

S. S. Agaian, The Univ. of Texas at San Antonio (United States); R. Sartor, Jr., Interdisciplinary Solutions (United States)

In the process of analyzing the surfaces of 3d scanned objects, it is desirable to perform per-vertex calculations on a region of connected vertices, much in the same way that 2d image filters perform per-pixel calculations on a window of adjacent pixels. Operations such as blurring, averaging, and noise reduction would be useful for these applications, and are already well-established in 2d image enhancement. In this paper, we present a method for adapting simple windowed 2d image processing operations to the problem domain of 3d mesh surfaces. The primary obstacle is that mesh surfaces are usually not flat, and their vertices are usually not arranged in a grid, so adapting the 2d algorithms requires a change of analytical models. First we characterize 2d rectangular arrays as a special case of a graph, with edges between adjacent pixels. Next we treat filter windows as a limitation on the walks from a given source node to every other reachable node in the graph. We tested the common windowed average, weighted average, and median operations. We used 3d meshes comprised of sets of vertices and polygons, modeled as weighted undirected graphs. The edge weights are taken as the Euclidean distance between two vertices, calculated from their XYZ coordinates in the usual way. Our method successfully provides a new way to utilize these existing 2d filters. In addition, further generalizations and applications are discussed, including potential applications in any field that uses graph theory, such as social networking, marketing, telecom networks, epidemiology, and others.

8406-25, Poster Session

Penetration tests in next generation networks

F. Rezac, M. Voznak, Technical Univ. of Ostrava (Czech Republic)

The paper deals with a penetration tests in Next Generation Networks, we developed testing tool to verify if the target SIP server (key component of NGN) is adequately secured and protected. The system tests the SIP element for several best-known attacks which currently appear and it compiles evaluation of its overall security on the basis of successfully or unsuccessfully penetrations. The paper describes the applications and algorithms that are used by penetration test system and the conclusion consists recommendations and guidelines to ensure effective protection against SIP server threats.

8406-26, Poster Session

Multispectral palmprint recognition by kernel associative memory-based computational model and finite ridgelet transform

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Due to low-cost, user-friendly and reliable one, palmprint recognition has been established itself a very accurate solution for a range of access control applications and identity verifications. Several studies for palmprint recognition have been made on improving performance of the system by palmprint images taken under visible light. However, in the last few years, thrust for robust palmprint system has begun with multispectral palm images. These multispectral palm images which are captured under visible and infrared light with different wavelengths show best substitution of visible ones by improving system performance further with very little error rates.

In this paper, we advocate a hierarchical kernel associative memory (KAM) based computational model for robust multispectral palmprint recognition with finite Ridgelet transform representation. To characterize multispectral palmprint image, Finite Ridgelet Transform is used to achieve a very compact representation of linear singularities and the FRIT captures the singularities along lines and edges. Finite Ridgelet Transform is used to represent the multispectral palmprint image and it is then modeled by Kernel Associative Memories. Finally recognition scheme is thoroughly tested with a benchmarking multispectral palmprint database CASIA. For recognition purpose Bayesian classifier is used. The experimental results exhibit robustness of the proposed system under different wavelengths.

8406-27, Poster Session

iPhone examination with modern forensic software tools

T. Hoene, S. Luttenberger, R. Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of the paper is to show the usefulness of modern forensic software tools for iPhone examination.

In particular, we focus on the new version of Elcomsoft iOS Forensic Toolkit and compare it with Oxygen Forensics Suite 2011 regarding functionality, usabillity and capabilities.

It is shown how these software tools works and how capable they are in examining non-jailbreaked and jailbreaked iPhones.

8406-28, Poster Session

A manifold learning-based identification of latent variations in root cross sections of plants

S. Chakravarty, SGT, Inc. (United States); M. Banerjee, Georgia Gwinnett College (United States)

A fundamental aim of developmental plant biology is to understand how the three-dimensional morphology of plants arises through cellular mechanisms. However, traditional anatomical studies of plant development have mainly relied on two-dimensional images. Three dimensional properties of plant structures are then inferred indirectly by extrapolatory methods. Though this may be sufficient for some aspects of plant biology, deeper understanding of plant growth and function increasingly requires at least some amount of three dimensional measures. They can be then stained by chemicals to express morphology by particular stain colors. Recent techniques of voxel imaging of plants include Confocal Microscopy and Optical Coherence Microscopy. They both have constraints on a maximum specimen depth of around 2 to 5 mm. Thus parameters like uniformity of illumination and thickness of the specimen become critical for these optical based voxel imaging modalities. Unfortunately these are also the causes of major variations.

The variation of thickness of specimen can be interpreted as an effect which increases the latent dimensionality of the data. Addressing the variability due to specimen thickness can then be viewed in a manifold learning framework, wherein it is assumed that the data of interest lies on an embedded manifold within the higher-dimensional space and can be visualized in low dimensional space, using manifold learning constraints.

In this work we propose the following approach. Initially image based uneven illumination correction methods are used to address illumination variation of the raw data. Spatial processing of the root cross sections is then performed to identify the different anatomical regions. Subsequently, feature vectors are generated from the different identified anatomical regions of the root cross section. These feature vectors are then trained on various manifolds to identify suitable manifold and dimensionality. Classification of the root cross sections is performed afterwards across samples to verify the suitability of the selected manifold as a viable solution for the observed slice thickness variations.The experimental results presented in this paper will demonstrate the effectiveness of our proposed method.

8406-29, Poster Session

Forensic determination of burner serial number placed on DVD-R(W) optical disks

F. Irmler, K. Kröger, R. Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of this paper is to demonstrate the possibility of forensic determination of DVD-R(W) disks regarding the serial number of the used DVD burner.

As it was already shown that the burner identification (serial number and type of burner) works for CD ROMs, it was largely unknown that this burner identification works for DVD-R(W) as well when special drives and special software is used.

8406-30, Poster Session

Computer-assisted machine-to-human protocols for authentication of a RAM-based embedded system

A. Idrissa, A. Aubert, T. Fournel, Lab. Hubert Curien (France)

Mobile readers used for optical identification of manufactured products can be tampered in different ways, with hardware Trojan or by powering up with fake configuration data. How a human verifier can authenticate the reader to be handled for goods verification?

In this paper, two cryptographic protocols are proposed to achieve through a trusted auxiliary machine, the verification of a RAM-based system. Such a system is assumed to be composed of a RAM memory and a secure block (in practice a FPGA or a configurable microcontroller). The system is connected to an input / output interface and contains a Non Volatile Memory where the configuration data are stored. Except the secure block, all the blocks are exposed to attacks.

At the registration stage of the first protocol, the MAC of both the secret and the configuration data, denoted M0 is computed by the mobile device without saving it then transmitted to the user, in a secure environment. At the verification stage, the reader which is challenged with nonces sends MACs / HMACs of both nonces and MAC M0 (to be recomputed), keyed with the secret. These responses are verified by the user through a trusted auxiliary MAC computer unit. Here the verifier does not need to tract a (long) list of challenge / response pairs as the participation of the human user to the authentication process is increased. In counterpart the secret has to be shared with the auxiliary unit.

This constraint is relaxed in a second protocol directly derived from Fiat and Shamir's scheme.

8406-31, Poster Session

Analysis methods of Mac OS X with commercial forensic software: an overview

K. Kröger, R. Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of the paper is to show the usefulness of modern forensic software tools for forensic analysis of Mac OS X computers.

In particular, we focus on the new version of MacForensicsLab and blackbagtech BlackLight.

It is shown how these software tools work and how capable they are in examining Mac OS X computers.

8406-32, Poster Session

Forensics of geodata collected by various mobile devices

K. Kröger, S. Sack, R. Creutzburg, Fachhochschule Brandenburg (Germany)

This paper gives an overview of the used technologies, the extraction and the analysis of stored geodata collected by various mobile devices, e.g. TomTom and Navigon navigation systems, built-in car navigation systems, iOS and Android in mobile devices.

The study shows how stored data can be extracted and examined.

The main aspect of this paper is the analysis of geodate storage by various mobile devices, their differences and possibilities for the forensic use of the extracted data.

8406-33, Poster Session

Joint context prediction for covert data merging

R. E. Metzler, The Univ. of Texas at San Antonio (United States)

Parallel adaptive predictors simultaneously model a secret text and a cover image plaintext to provide high density data hiding through prediction error coding. The predictors utilize novel techniques, such as Lyndon word merging (LWM) for linear context modeling and sparse transform estimation (STE) for generalized spatial modeling. Because these predictors generate stochastic estimates, concurrent compression of the secret text with an entropy encoder is convenient and creates the added benefit that the secret text appears to be evenly distributed white noise within the cover image. This allows the system to achieve embedment densities greater than one bit per pixel. Also, because the embedded data is noise-like, the merged text is also resistant to tamper detection. In the case of universality of the predictors, a maximal amount of secret text data can be embedded for a given distortion rate, which indicates that the system can either be implemented in reversible (lossless) modes or irreversible, higher density modes. Simulations embedding text data into natural gray scale images show embedment rates up to 1.5 bits per pixel can be obtained with minimal distortion.

8406-34, Poster Session

Arabic writer identification based on diacritic's features

M. Maliki, N. Al-Jawad, S. A. Jassim, The Univ. of Buckingham (United Kingdom)

Natural languages like Arabic, Kurdish, Farsi (Persian) and Urdu have many features, which make them different from other languages like Latin's script. One of these important features is diacritics. These diacritics are classified as: compulsory like dots which are used to identify/differentiate letters, and optional like short vowels which are used to emphasis consonants. Most indigenous and well trained writers often do not use all or some of these second class of diacritics, and expert readers can infer their presence within the context of the writer text.

In this paper, we investigate the use of diacritics shapes and other characteristic as parameters of feature vectors for Arabic writer identification/verification. Segmentation techniques are used to extract the diacritics-based feature vectors from examples of Arabic handwritten text.

We shall present results of evaluation test carried out on an in-house database of 100 writers as well as a set of 100 writers from IFN/ENIT benchmark database. We shall demonstrate the viability of using diacritics for writer recognition.

8406-35, Poster Session

Enhancement and analysis of fused thermal and RGBD data

M. O. Blanton, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

The fusion of thermal data and RGBD (RGB and 3-dimensional Depth) data will be analyzed and researched for the purpose of extrapolating thermal conductance and other thermal properties within a scanned environment. This will allow for the determination of energy assessments regarding structural boundaries, the effectiveness of insulation, leakages of heat, water and refrigerant, and computing the true value of observed thermal losses/gains as they are related not only to thermal properties, but geometries as well. The data generated from this analysis can be used in many domains and process evaluations.

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8407-01, Session 1

Spectral and spatial algorithm architecture for classification of HSI and lidar

R. S. Rand, T. S. Khuon, National Geospatial-Intelligence Agency (United States)

A generic architecture for neural net multi-sensor data fusion is introduced and analyzed. The architecture consists of a set of independent sensor neural nets, one for each sensor, coupled to a fusion net. Each sensor is trained (from a representative data set of the particular sensor) to map to a hypothesis space output. The decision outputs from the sensor nets are used to train the fusion net to an overall decision. The architecture is also applied to a data fusion experiment involving the multi-sensor observation of the Gulfport area during a November 2010 airborne collection of Lidar and hyperspectral data. Initially to begin the processing, the 3D point cloud Lidar data is classified based on the multi-dimensional mean-shift segmentation and classification into clustered detections or objects. Similarly, the multi-band hyperspectral data is spectrally classified by the stochastic equalization maximization into a classification map containing pixel classes. For sensor fusion, spatial detections and spectral detections complement each other. They are fused into final detections by a cascaded neural network, which consists of two levels of neural nets. The first layer is the sensor level consisting of two neural nets: spatial neural net and spectral neural net. The second level consists of a single neural net, that is the fusion neural net. The success of the system in utilizing sensor synergism for an enhanced classification and detection is clearly demonstrated.

8407-02, Session 1

Effects of aberrations on image reconstruction of data from hybrid intensity interferometers

J. Murray-Krezan, P. N. Crabtree, Air Force Research Lab. (United States)

Intensity interferometery (II) holds tremendous potential for remote sensing of space objects. We investigate the properties of a hybrid intensity interferometer concept where information from an II is fused with information from a traditional imaging telescope. Although not an imager, hybrid intensity interferometery measurements can be used to reconstruct an image. In previous work we investigated the effects of poor SNR on this image formation process. In this work, we go beyond the obviously deleterious effects of SNR, to investigate reconstructed image quality as a function of artifacts in the image formation process, for a hybrid intensity interferometer. The benefits to fusion of assumed perfect-yet-partial a priori information with traditional intensity interferometery measurements are explored and shown to result in increased sensitivity and improved reconstructed image quality.

8407-03, Session 1

Multisource taxonomy-based classification using the transferable belief model

W. J. Farrell III, A. M. Knapp, Lakota Technical Solutions, Inc. (United States)

This paper addresses the problem of multi-source object classification in a context where classified objects are part of a known taxonomy and the classification sources report at varying levels of specificity. An example of this type of problem might be the classification of non-cooperative airborne targets, represented in the MIL-STD-6016 taxonomy, using a variety of heterogeneous sensors. This problem must consider several technical challenges: (1) support fusion of heterogeneous classification inputs, (2) provide a computationally scalable approach that accommodates taxonomy's with thousands of leaf nodes, and (3) provide outputs that support tactical decision aides and are suitable inputs for subsequent fusion processes. This paper presents an approach that employs the Transferable Belief Model (TBM), Pignistic Transforms, and Bayesian Fusion to address these challenges. Specifically, the TBM is used as the mathematical framework for representing classification beliefs from reporting sources, propagating beliefs throughout the taxonomy in a computationally scalable way, and computing plausibility and support. The Pignistic Transform is used to create probabilities (from plausibility and support) for any chosen hypothesis space within the taxonomy. Finally, Bayesian Fusion is applied to the Pignistic Probabilities to combine the classification information from multiple sources. In addition, the Probabilistic Information Content (PIC) measure is used to adaptively select the hypothesis space to be used for output of the final classification hypotheses. This adaptive approach reports fused classifications at various levels of specificity, depending upon the specificity and information content of the multi-source inputs.

8407-04, Session 1

Computationally efficient Bayesian fusion

B. R. La Cour, J. M. Aughenbaugh, The Univ. of Texas at Austin (United States)

A Bayesian approach to tracking provides a natural solution to the heterogeneous fusion problem. By probabilistically modeling the information content of each sensor's measurements through a likelihood function, each sensor's contribution is placed on a common footing. Furthermore, by fusing at the sensor level, such an approach can allow for the localization of targets that could not otherwise be found by any single sensor. Finally, by working in a physical state space, one can achieve situational awareness in the form of a geocentric picture with an intuitive representation of uncertainty.

The general Bayesian fusion problem can be computationally demanding, and traditional approaches have shied away from a direct, grid-based solution. In this paper, we describe the progress we have achieved in developing a computationally efficient, grid-based Bayesian fusion tracking system. In our approach, the probability surface is represented by a collection of multidimensional polynomials, each computed adaptively on a grid of cells representing state space.

Using a hybrid particle/grid approach and knowledge of the grid structure, we are able to evolve the grid forward in a time that increases only linearly with the number of grid cells. Furthermore, using a measurement-based sampling method with a Delaunay triangulation, even narrow likelihood functions may be accurately evaluated. Finally, we adjust the polynomial order in each cell to minimized the total number of degrees of freedom. We present an application of this system to the problem of tracking a submarine target using a field of active and passive sonar buoys.

8407-05, Session 1

Automated tracking of 2D optical and 3D flash lidar objects

R. J. Poore, R. L. Tutwiler, D. L. Hall, The Pennsylvania State Univ. (United States)

Complex object interactions and behaviors pose many challenges to existing tracking algorithms. Successful tracking of these objects and their behaviors can provide great insight into the intentions of a group of objects for security reasons, as well as, for situational awareness. This work presents an automated tracking system that tracks multiple 2D or 3D objects in a real-life scene while they interact, split, collide, deform, occlude, and move in various different motions. The system will detect, segment, track, and predict the objects motion by combining various classic image-processing techniques with a modified version of an energy contour minimization algorithm that incorporates an adaptive interacting multiple model estimator previously used for tracking biological cells. The system will also analyze the overall pattern of all the objects for classifying and identifying group intentions. The results of this work are applicable to a variety of applications pertaining to the detection of security threats.

8407-06, Session 2

Cross layers decision making and fusion model in layered sensing systems

A. I. Khoshnaw, S. Zein-Sabatto, M. Malkani, Tennessee State Univ. (United States)

Layered sensing systems involve operation of several layers of sensing with different capabilities integrated into one whole system. The integrated layers of sensing must share information and local decisions across layers for better situation awareness. This research focused on the development of a model for decision making and fusion at the information level in layered sensing systems using the cloud model for uncertainty processing. In the research, the addition of a new processing level to the Joint Directors of Laboratories (JDL) processing model was proposed. The new processing level was called “Information Assessment, Fusion, and Control (IAFC)”. Through this level, the different layers of a layered sensing system evaluate information about a given situation in terms of threat level and make a decision. The information assessment and control processing module was able to exchange information in order to determine the overall situation’s threat level among all layers. Situation assessment, decision making and the fusion of the uncertain decisions together to a unified decision was implemented using the cloud model of uncertainty processing methodology. Using this methodology, a cognitive element was added to the process of information assessment module leading to more accurate situation awareness. The developed system was implemented and tested on a multi layer system using the ATR-TSU test-bed. MATLAB environment was used for developing and testing of the decision making and fusion model.

8407-08, Session 2

Multilayer network centric fusion architecture and optimality

O. Aboutalib, System Analysis and Sensor Fusion Co. (United States) and California State Univ., Fullerton (United States)

There is a critical need by the United State Military to move from a “platform centric” fusion to a “multi-layer network centric” fusion where the nodes of the network have a wide range of representations including multi-layer surveillance platforms with different types of on-board surveillance sensors, various weapons systems with different types of acquisition and terminal sensors, and even dismount soldiers on the ground. Each node is required to receive the needed information in a timely manner to meet specific tactical or strategic objectives. Given the dynamics of multi-layer networks and the abundance of multi-sensor/multi-platform data, new challenges emerge, including: 1) Cross-sensor/cross-platform cueing; 2) the selection of the appropriate fusion level; 3) the creation of consistent common/relevant operating pictures; 4) dealing with the various levels of coupling among decision nodes; 5) data dependency; 6) fusion optimality to ensure that there is always performance gain due to fusion; and 7) GPS denial. In this paper, we developed a fusion architecture that addresses the major challenges of multi-sensor/multi-platform fusion in a network-centric environment, and the creation of consistent common/relevant operating pictures. We will also present an optimal network centric decision-level fusion that maximizes the joint decision probability utilizing all available information at each node that performs fusion such as historical measures, the credibility of the decision making process at each node, and the associated degree of learning of each target in the target set and the corresponding figure-of-merit in each decision.

8407-09, Session 2

Leveraging provenance to improve data fusion in sensor networks

G. Dogan, T. Brown, The City Univ. of New York (United States); E. Seo, T. F. Abdelzaher, Univ. of Illinois at Urbana Champaign (United States)

In networks with distributed nature, data is not stored at a central database. Nodes keep relevant data and data fusion is done at the intermediate nodes as data from several sources arrive. In these networks, it is difficult to get further properties of data (such as which node has sent it, what kind of data it is) when data fusion is being done as data is not central. In this case, a distributed data retrieval mechanism which is aware of properties of data is needed to combine data at different nodes. In traditional networks data fusion is done without considering node specific metadata however in our model data fusion is done more intelligently by using the provenance. For instance in a target localization network, there are many nodes detecting a target, however their data has different value based on the node’s location, energy and type. With our model, it is possible to give less weight to the data coming from a dying node and give more weight to a node which is closer to the target by using provenance data kept at the nodes. Hence data fusion gives more accurate, timely and energy efficient result.

8407-10, Session 2

Analysis of decision fusion algorithms in handling uncertainties for integrated health monitoring systems

S. Zein-Sabatto, M. Bodruzzaman, Tennessee State Univ. (United States)

Although low-level data and information fusion methods improve the accuracy and robustness of decision-making about events, there is a clear justification and need for decision-fusion at the highest processing level if integrated systems are of interest. Several decisions at low-level of abstraction may be produced by different decision-makers, however, decision-level fusion is required at the final stage of the process to provide accurate assessment about the system as a whole. An example of such integrated systems with complex decision-making scenarios is the health monitoring of an aircraft. Several decisions can be produced by different diagnostics algorithms monitoring the aircraft’s engines and structure. To better understand and assess events happing in the aircraft, decisions made by these diagnostics algorithms must be fused to provide an accurate picture about the true health of the aircraft. Profound understanding of the characteristics of the decision-fusion methodologies is a crucial step for successful implementation of decision-fusion systems. In this paper, two issues of importance to the decision-fusion systems are addressed. First, major decision fusion

methods reported in the literature are surveyed and grouped into classes. Then, their theoretical basis and performance analysis were conducted. Finally, candidate algorithms from the different fusion methodologies were selected and their performances were tested on synthetic decisions with various complexities. Two modeling methodologies were used for creating synthetic decisions. We made sure that the synthetic-decisions were unbiased for fair performance comparison of the selected decision-fusion algorithms. Implementation of the selected fusion algorithms on aircraft health monitoring will be reported.

8407-11, Session 3

Multirobot autonomous landmine detection using distributed multisensor information aggregation

J. Jumadinova, R. Dasgupta, Univ. of Nebraska at Omaha (United States)

Autonomous detection of landmines using sensors is a crucial operation in assisting humanitarian demining and reducin high-risks to human deminers. Unfortunately, landmine detection sensors like infra-red heat sensors, metal detectors and ground penetrating radar are susceptible to significant noise depending on environment and ambient conditions such as moisture, sunlight, temperature, vegetation, etc. This results in significant false positives when these sensors are used individually. We posit that the accuracy of autonomous landmine detection can be improved by assigning sensors of different types to an object that could potentially be a landmine, over a period of time so that the uncertainty in identifying the object gets successively reduced. In this paper, we report our ongoing research results on this, done as part of the ONR-funded COMRADES project. We consider a scenario where a group of robots each equipped with a different type of landmine detection sensor, or, sensors with different degrees of accuracies are deployed into a region that could potentially contain landmines. We propose a novel, market-based approach for multi-sensor information fusion using a distributed information aggregation technique, called a prediction market, to perform autonomous landmine detection with higher accuracies. Our technique includes a utility-driven approach that de-incentivizes malicious sensors from misreporting their perceived information, and, a decision-maker that uses the domain knowledge to make decisions that promise the highest expected reduction in the uncertainty of identifying a landmine. We will report experimental results verifying the performance of our technique and its comparison with other state-of-the-art techniques in this area.

8407-12, Session 3

Architectural design and support for knowledge sharing across heterogeneous MAST systems

R. C. Arkin, S. Garcia-Vergara, S. G. Lee, Georgia Institute of Technology (United States)

In research as part of the Army Research Lab Collaborative Technology Alliance for MicroAutonomous Systems Technology (MAST), we are developing foundational capabilities to provide knowledge sharing across widely heterogeneous platforms: small crawlers equipped with airflow sensors and micro gas chromatographs; and microflyers fitted with millimeter wave radar and infrared imagers. The research question we are pursuing is how can such robotic systems with such radically different views of the world share information in ways that allow for effective distributed mission tasking and completion.

We continue to exploit our novel approach to this problem that leverages our prior work [1] in the conceptual spaces framework developed by Gardenfors [2]. This involves the creation of an abstract sensor layer, which is mapped onto a platform-specific conceptual space that defines real-world objects in the context of the sensory capacity of each robotic agent. These in turn communicate high-level symbolic concepts along with a robot id and target location couched in an egocentric or allocentric frame of reference.

Specific mission scenarios involve multi-robot search, detection, and operator alert for possible biohazards or chemical weapons within an interior structure using teams of microflyers and crawlers equipped with highly disparate and somewhat esoteric sensor suites.

[1] Ulam, P., Kira, Z., Arkin, R., and Collins, T., “Mission Specification and Control for Unmanned Aerial and Ground Vehicles for Indoor Target Discovery and Tracking”, SPIE Defense, Security, and Sensing, 2010.

[2] Gardenfors, P. (2000), Conceptual Spaces: The Geometry of Thought, MIT Press.

8407-13, Session 3

Navigation of uncertain terrain by fusion of information from real and synthetic imagery

D. M. Lyons, P. Nirmal, Fordham Univ. (United States)

We consider the scenario where an autonomous platform that is searching an area for a target may observe unstable masonry or may need to travel over unstable rubble. One approach is to provide a general set of reactive behaviors that produce reasonable behavior under these uncertain and dynamic conditions but which may produce behavior that works against long-term goals.

We investigate combining behaviors with the Cognitive Robotics paradigm of rehersal to produce a hybred reactive-deliberative approach for this kind of scenario.

In previous work we have proposed an approach, ADAPT, that leverages the state of the art in physics-engines for gaming so that perception becomes part of the problem solving process. A physics-engine is used to numerically simulate outcomes of complex physical phenomena, and to fuse the graphical image results with the image information from visual sensing. This approach is possible because of the speed and availability of physics simulations. However, these results were for a stationary robot platform.

In the current paper, we extend the work to handle the motion of a mobile platform through an indoor environment. We will assume that the static components of the scene, walls and floors, have been modelled in the physics engine. However, dynamic objects can appear, are identified as unexpected, and the physics engine is used to predict their behavior, and to select motion that is both safe and works towards long-term goals.

8407-14, Session 3

Allothetic and idiothetic sensor fusion in rat-inspired robot localization

A. Weitzenfeld, Univ. of South Florida Polytechnic (United States); J. Fellous, The Univ. of Arizona (United States); A. Barrera, Instituto Tecnológico Autónomo De México (Mexico); G. Tejera, Univ. de la República (Uruguay)

We describe a spatial cognition model based on the rat’s brain neurophysiology as a basis for new robotic navigation architectures. The model integrates allothetic (external visual landmarks) and idiothetic (internal kinesthetic information) cues to train either rat or robot to learn a path enabling it to reach a goal from multiple starting positions. It stands in contrast to most robotic architectures based on SLAM, where a map of the environment is built to provide probabilistic localization information computed from robot odometry and landmark perception. In our work we describe a spatial cognition model and maze experiments exploiting individual and combined allothetic and idiothetic cues during target learning and place recognition experiments in both rats and robots. Allothetic cues suffer in general from perceptual ambiguity when trying to distinguish between places with equivalent visual patterns, while idiothetic cues suffer from imprecise motions and limited memory recalls. We experiment with both types of cues in different maze configurations by training rats and robots to find the goal starting from a fixed location, and then testing them to reach the same target from new starting locations. We show that the robot, after having pre-explored a maze, can find a goal with improved efficiency, and is able to (1) learn the correct route to reach the goal, (2) recognize places already visited, and (3) exploit allothetic and idiothetic cues to improve on its performance. We finally contrast our biologically-inspired approach to more traditional robotic approaches and discuss current work in progress.

8407-15, Session 3

Using a virtual world for robot planning

D. P. Benjamin, Pace Univ. (United States); D. M. Lyons, Fordham Univ. (United States); J. V. Monaco, L. Yixia, Pace Univ. (United States)

We are building a robot cognitive architecture that constructs a realtime virtual copy of itself and its environment, including people, and uses the model to process perceptual information and to plan its movements. This paper describes the structure of this architecture, and provides examples of its performance in dynamic environments.

The software components of this architecture include PhysX for the virtual world, OpenCV and the Point Cloud Library for visual processing, and the Soar cognitive architecture which controls the perceptual processing and task planning. The RS (Robot Schemas) language is implemented in Soar, providing the ability to reason about concurrency and time. This Soar/RS component controls visual processing, deciding which objects and dynamics to render into PhysX, and the degree of detail required for the task.

As the robot runs, its virtual model diverges from physical reality, and errors grow. The Match-Mediated Difference component monitors these errors by comparing the visual data with corresponding data from virtual cameras, and notifies Soar/RS of significant differences, e.g. a new object that appears, or an object that changes direction unexpectedly.

Soar/RS can then run PhysX much faster than realtime and search among possible future world paths to plan the robot's actions. We report experimental results in indoor environments.

8407-16, Session 3

Using arm and hand gestures to command robots during stealth operations

A. Stoica, Jet Propulsion Lab. (United States)

For scenarios of silent operations in night/low visibility conditions the use of voice commands and vision-based gesture interpretation techniques are ruled out as primary means of capturing soldier's intent, and becomes preferable to capture the command gestures with an intuitive interface that provides fast, high DOF information, while in the same time leaves the operator's hands unencumbered.

Targeted at using bio-signal inputs to set navigation and manipulation goals for the robot (say, simply by pointing), we developed a system around an electromyography (EMG) "BioSleeve", a high density sensor array (a 32 sensor version under development will supersede the current 16 sensor version in use), for robust, practical signal collection from forearm muscles. The EMG sensor array data is fused with data provided by inertial measurement units (IMU). The BioSleeve system is demonstrated on the recognition of static (e.g. palm facing front, fingers upwards) and on dynamic gestures (e.g. hand wave). In preliminary experiments, over 96% correct recognition was achieved on 10 dynamic gestures, using same person, and without removal/replacement of sensor sleeve. The demonstration uses a set of 5 Landroid robots, which are commanded individually or in group. The paper describes the algorithms for decoding robot commands from biological signals and IMU data. It also describes an adaptive autonomy architecture that allows users to use the same interface to set high-level goals, to teleoperate the robot, or to send mid-level commands. For situations where voice commands are acceptable, the main value of BioSleeve shifts towards being the more natural means to indicate locations in the operation space, etc., as well as to providing alternative channel redundancy for reliability/confirmation of commands.

8407-17, Session 4

Multimodal biometric approach for cancelable face template generation

P. P. P. Paul, S. Bazazian, M. Gavrilova, Univ. of Calgary (Canada)

Due to the rapid growth of biometric system and technology, template protection becomes crucial to protect the biometric security system from terrorists and criminals. Cancelable biometrics is emerging as one of the best solutions to secure the biometric identification and verification system. We present a novel technique for robust cancelable template generation algorithm that takes advantage of the multimodal biometric using feature level fusion. Feature level fusion of different facial features is applied to generate the cancelable template. A proposed new algorithm based on the multi-fold random projection and fuzzy communication scheme is used for this purpose. In cancelable template generation one of the main difficulties is keeping interclass variance of the feature. We have found that interclass variations of the features which are lost during multi fold random projection can be recovered using fusion of different feature subsets and projecting in a new feature domain. Applying the multimodal technique in feature level, we enhance the interclass variability hence improving the performance of the system. We have tested the system for classifier fusion for different feature subset and different cancelable template fusion. Experiments have shown that cancelable template improves the performance of the biometric system compared with the original template.

8407-18, Session 4

Fusion of pose and appearance manifolds for tracking in cluttered environments

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The task of tracking targets in urban environments presents several unique challenges. There are multiple targets and occlusions, as well as a high level of clutter in scenes. Combined imagery from urban scenes results in large data sets with high dimensionality. Adding to this data complexity is the use of flash LIDAR, which creates 2.5D images of a scene. Directly using this high dimensional data often results in poor performance in both object matching and tracking algorithms. In order to efficiently use this data and make sense of a cluttered scene, we must reduce the dimensionality of the feature space. Manifold learning is one method to accomplish this task. Its primary benefit is being able to reduce the dimensionality of features that are not linearly related or even of the same feature type. Thus, we can generate a concise description of objects in a scene and their motion. Specifically, we wish to use appearance and pose models to characterize targets (people) in a scene. The structure from motion problem is largely avoided by the use of flash LIDAR. This approach gives us a good estimate of target pose and orientation. Visual trackers capture the corresponding target appearance. Manifold fusion allows for improved performance in cluttered, object-rich environments.

8407-19, Session 4

Context-based gait recognition

S. Bazazian, P. P. P. Paul, M. Gavrilova, Univ. of Calgary (Canada)

Identifying people by their walking style or gait recognition has recently become a very popular topic in the field of biometrics. However, the main

downside is the insufficient recognition rate especially in the presence of low quality samples. The main focus of this paper is to investigate how the performance of a gait recognition system can be improved using additional information about behavioral patterns and the context in which videos have been taken. The obtained results show that fusing this new metadata will always improve the performance of the system at a very low cost. The amount of improvement depends on the distinctiveness of the behavioral patterns and the quality of the gait samples. Using the appropriate distinctive behavioral models it is possible to achieve 100% recognition rate.

8407-20, Session 4

Human face identification using multisource fusion

M. K. Bhowmik, D. Bhattacharjee, D. K. Basu, M. Nasipuri, Jadavpur Univ. (India)

This paper demonstrates the comparison of two methods for human face recognition one using feature level image fusion of multiresolution level-2 wavelet coefficients from thermal and visual face images and second one is decision fusion of classifiers. Wavelet filter based fusion techniques have been used here for fusion, which is well-suited to manage different image resolution and allows the image decomposition in different kinds of coefficients, while preserving the image information without any loss. In feature level fusion (method-I), matrices with wavelet coefficients are fused and then classified using a multi-layer perceptron (MLP) after reduction of dimensions by Principal Component Analysis (PCA). In decision level fusion (method-II) decisions of different classifiers (multi-layer perceptron neural network and radial basis function neural network) have been used. First of all, distances have been calculated between the feature vectors extracted from test face image and that of probe images. Finally, decisions of two neural networks have been combined together using sum rule of decision fusion. Sum rule has been applied separately for all the class images. For experiments IRIS Thermal / Visual Face Database has been used, which contains images with varying illumination, facial expression and pose. Using feature level fusion, 2 classes have been recognized 100% and average recognition rate is 87.28%. Whereas, decision fusion gives 100% recognition rate for 4 classes and average recognition rate is 94.95% which is 7.67% more than feature level fusion scheme. Maximum recognition rates have been obtained especially in case of varying illuminations and expressions.

8407-21, Session 4

Real-time threat assessment for critical infrastructure protection using evidential reasoning: techniques for handling data incest

R. Brandon, J. Varndell, S. Page, Waterfall Solutions Ltd. (United Kingdom)

This paper presents a novel application of Evidential Reasoning to Threat Assessment for critical infrastructure protection. A novel fusion algorithm based on the PCR5 Dezert-Smarandache fusion rule is proposed which fuses alerts generated by a vision-based behaviour analysis algorithm and a-priori watch-list intelligence data. The fusion algorithm produces a prioritised event list according to a user-defined set of event-type severity or priority weightings. Results generated from application of the algorithm to real data and behaviour analysis alerts captured at Heathrow Airport under the EU FP7 SAMURAI programme are presented. A web-based demonstrator system is also described which implements the fusion algorithm in real-time. It is shown that this system significantly reduces the data deluge problem, and directs the user's attention to the most pertinent alerts, enhancing their Situational Awareness. The end-user is also able to alter the perceived importance of different event types in real-time, allowing the system to adapt rapidly to changes in priorities as the situational evolves. One of the key challenges associated with fusing information deriving from intelligence data is the issue of Data Incest. Techniques for handling Data Incest within Evidential Reasoning frameworks are proposed, and comparisons are drawn with respect to Data Incest management techniques that are commonly employed within Bayesian Data Fusion frameworks (e.g. Covariance Intersection). The challenges associated with simultaneously dealing with conflicting information and Data Incest in Evidential Reasoning frameworks are also discussed

8407-22, Session 5

Automatic and generic mosaicing of multisensor images: an application to Pleiades HR

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The CNES (French Space Agency) has specified and developed a fully automatic mosaicing processing unit, in order to generate satellite image mosaics under operational conditions. This tool can automatically change each input image into a common geometry, homogenize the radiometry, and generate orthomosaics using stitching lines.

Its first operational use will be in PLEIADES operational Image Processing Unit. PLEIADES High Resolution, a two-satellite Earth Observation constellation, offers a panchromatic nadir resolution of 70 cm and a swath of 20 km with high agility to ensure the coverage of wide areas using adjacent depointed acquisitions in order to generate 60 km * 60 km (and more) mosaics from 20 km strips.

Beyond PLEIADES, this tool can process a significant variety of images for many types of use. Using plugins to customize the processing options, the tool offers several services such as spectral band registration, registration within input images including coming from different sensor, registration with automatically-taken reference control points or external ground control points, focal plane cartography, radiometric harmonization, time-based image superposition, stitching line computation and mosaic resampling. It is compliant with aerial and satellite imagery.

This paper will first present the design of the mosaicing tool and describes the processing workflow and its additional capabilities and applications.

As PHR1A (PLEIADES first satellite) will be launched at the end of 2011, this paper will also show the first operational outputs of this automatic mosaicing tool.

8407-23, Session 5

Adaptive optimal spectral range for dynamically changing scene

E. Pinsky, A. Siman-Tov, D. Peles, Rafael Advanced Defense Systems Ltd. (Israel)

A novel multispectral video system that continuously optimizes both its spectral range channels and the exposure time of each channel independently, under dynamic scenes, varying from short range- clear scene through long range- poor visibility, is currently being developed. Transparency and contrast of high scattering medium of channels with spectral ranges in the near infrared is superior to the visible channels, particularly to the blue range. Longer wavelength spectral ranges that induce higher contrast are therefore favored. Images of 3 spectral channels are fused and displayed for (pseudo) color visualization, as an integrated high contrast video stream.

In addition to the dynamic optimization of the spectral channels, optimal real-time exposure time is adjusted simultaneously and independently for each channel. A criterion of maximum average signal, derived dynamically from previous frames of the video stream is used (Patent Application - International Publication Number: WO2009/093110 A2, 30.07.2009). This configuration enables dynamic compatibility to

the optimal exposure time of a dynamically changing scene. It also maximizes the signal to noise ratio and compensates each channel for the specified value of daylight reflections and sensors response for each spectral range.

A possible implementation is a color video camera based on 4 synchronized, highly responsive, CCD imaging detectors, attached to a 4CCD dichroic prism and combined with a common, color corrected, lens. Principal Components Analysis (PCA) technique is then applied for real time "dimensional collapse" in color space, in order to select and fuse for clear color visualization, the 3 most significant spectral channels out of at least 4, characterized by high contrast and rich details in the image data.

8407-24, Session 5

Colour the INSight: combining a direct view rifle sight with fused thermal and image intensifier imagery

M. A. Hogervorst, C. Jansen, A. Toet, P. Bijl, TNO Defence, Security and Safety (Netherlands); P. Bakker, Thales Nederland B.V. (Netherlands); A. C. Hiddema, PHOTONIS Netherlands B.V. (Netherlands); S. van Vliet, Ministerie van Defensie (Netherlands)

We present the design and evaluation of a new demonstrator rifle sight viewing system containing direct view, red aim point and fusion of an (uncooled, LWIR) thermal sensor with a digital image intensifier. The goal is to create a system that performs well under a wide variety of (weather) conditions during daytime and nighttime and combines the advantages of various sensor systems. The Color-the-Night fusion method (Hogervorst & Toet, 2010) results in a color image with salient hot targets. It is implemented in real-time by the on-board processor. The demonstrator system has been evaluated in field trials with military observers performing detection and identification tasks. During daytime the addition of a thermal image to direct vision shows to be advantageous. At nighttime, the fusion of thermal and image intensified imagery results in increased situational awareness and improved detection of (hot) targets. The tests show that the technology needs to be further refined for identification of small (handheld) objects.

8407-25, Session 5

Synergistic use of very high-resolution SAR and optical data for mapping and target detection

V. Tsagaris, N. Fragoulis, C. Theoharatos, IRIDA Labs. (Greece)

The global space infrastructure is rapidly evolving and provides very large potential for synergistic use of optical and radar data in order to develop near real time operational capabilities. For Europe, the GMES Sentinels will provide medium or high resolution data that will be available for end users while in the same time more advanced SAR satellites, such as Cosmo-SkyMed and TerraSAR-X are in orbit. Thus, a great need arises for fusion method that could combine these different technologies and their key characteristics.

The purpose of this work is to report and compare different fusion methods for synergistic use of very high resolution (VHR) synthetic aperture radar (SAR) data with optical imagery to produce value-added representations. Such representations could be further utilized in thematic mapping, topographic mapping or 3D visualization applications. The overall fusion approach will be based in two different approaches, the first one dealing with raw data fusion or often referred as pixel-level fusion while the second one in feature fusion.

In the first approach we rely on dimensionality reduction approaches like PCA that can be applied directly on the pixel values of the optical and the SAR data. The second approach is to derive specific areas of interest or detect targets using SAR data and compare or overlay the results in the optical imagery in order to achieve enhanced visual awareness for the end-user. An example is the identification of targets in a sea clutter background (ships) and the representation in the corresponding optical high resolution scene.

8407-26, Session 6

Advances in data representation for hard/soft information fusion

J. C. Rimland, D. M. Coughlin, D. L. Hall, J. L. Graham, The Pennsylvania State Univ. (United States)

Information fusion is becoming increasingly human-centric. While past systems typically relegated humans to the role of analyzing a finished fusion product, current systems are exploring the role of humans as integral elements in a modular and extensible distributed framework where many tasks can be accomplished by either human or machine performers. For example, "participatory sensing" campaigns give humans the role of "soft sensors" by uploading their direct observations or as "soft sensor platforms" by using mobile devices to record human-annotated, GPS-encoded high quality photographs, video, or audio. Additionally, the role of "human-in-the-loop", in which individuals or teams using advanced human computer interface (HCI) tools such as stereoscopic 3D visualization, haptic interfaces, or aural "sonification" interfaces can help to effectively engage the innate human capability to perform pattern matching, anomaly identification, and semantic-based contextual reasoning to interpret an evolving situation.

The Pennsylvania State University is participating in a Multi-disciplinary University Research Initiative (MURI) program funded by the U.S. Army Research Office to investigate fusion of hard and soft data in counterinsurgency (COIN) situations. In addition to the importance of this research for Intelligence Preparation of the Battlefield (IPB), many of the same challenges and techniques apply to health and medical informatics, crisis management, crowd-sourced "citizen science", and monitoring environmental concerns. One of the key challenges that we have encountered is the development of data formats, protocols, and methodologies to establish an information architecture and framework for the effective capture, representation, transmission, and storage of the vastly heterogeneous data and accompanying metadata (including capabilities and characteristics of human observers, uncertainty of human observations, "soft" contextual data, and information pedigree). This paper describes our findings and offers insights into the role of data representation in hard/soft fusion.

8407-27, Session 6

Human cognitive and perceptual factors in JDL level 4 hard/soft data fusion

J. C. Rimland, D. L. Hall, J. L. Graham, The Pennsylvania State Univ. (United States)

Utilization of human participants as "soft sensors" is becoming increasingly important for gathering information related to a wide range of phenomena including natural and man-made disasters, environmental changes over time, crime prevention, and other roles of the "citizen scientist." The ubiquity of advanced mobile devices is facilitating the role of humans as "hybrid sensor platforms", allowing them to gather data (e.g. video, still images, GPS coordinates), annotate it based on their intuitive human understanding, and upload it using existing infrastructure and social networks. However, this new paradigm presents many challenges related to source characterization, effective tasking, and utilization of massive quantities of physical sensor, human-based, and hybrid hard/soft data in a manner that facilitates decision making instead of simply amplifying information overload.

In the Joint Directors of Laboratories (JDL) data fusion process model, "level 4" fusion is a meta-process that attempts to improve performance of the entire fusion system through effective source utilization. While there are well-defined approaches for tasking and categorizing physical sensors, these methods fall short when attempting to effectively utilize a

hybrid group of physical sensors and human observers. While physical sensor characterization can rely on statistical models of performance (e.g. accuracy, reliability, specificity, etc.) under given conditions, “soft” sensors add the additional challenges of characterizing human performance, tasking without inducing bias, and effectively balancing strengths and weaknesses of both human and physical sensors.
This paper addresses the challenges of the evolving human-centric fusion paradigm and presents cognitive, perceptual, and other human factors that help to understand, categorize, and augment the roles and capabilities of humans as observers in hybrid systems.

8407-28, Session 6

Use of sonification in the detection of anomalous events

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It has been said that current intelligence and data analysis procedures yield little success, and in effect simply create digital landfills, as ever-increasing volumes and sources of data are collected, but rarely (if ever) understood or acted on in meaningful ways. While ideally information analysis would be a profession populated by skilled and seasoned workers, in reality such a position is more often entry-level, with high turnover rates, typically held by younger, less-skilled employees (who typically hold skills gained from operating computer gaming interfaces). Here, we explore a multi-modal rendering of data collected from the stock market and the twittersphere. Through a display that is primarily auditory (though visual elements also play a role), we show how these data sources can be fused and studied simultaneously. Anomaly detection is readily apparent, even to relatively naïve and musically untrained listeners. By designing a display that addresses the sensitivities of the human auditory system, we free the eyes of analysts for other tasks. A background soundtrack is rendered. The soundtrack is customizable, allowing the analyst to quickly create a “mix” of the information sources to be studied. Rather than requiring an operator’s visual attention focused on a monitor for extended periods, we capitalize on the auditory system’s sensitivities to periodicities, dynamic changes, and patterns. The rendering immediately strengthens an analyst’s situational awareness by capitalizing on normal, everyday hearing.

8407-29, Session 6

Homeland situation awareness through mining and fusing heterogeneous information from intelligence databases and field sensors

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One of the most felt issues in the defence domain is that of having huge quantities of data stored in databases and acquired from field sensors, without being able to infer information from them. Usually databases are continuously updated with observations, and are related to heterogeneous data. Deep and continuous analysis on the data could mine useful correlations, explain relations existing among data and cue searches for further evidences.

The solution to the problem addressed before seems to deal both with the domain of Data Mining and with the domain of high level Data Fusion, that is Situation Assessment, Threat Assessment and Process Refinement.

The focus of this paper is the definition of the most suitable architecture for a system adopting data mining techniques to adaptively discover clusters of information and relation among them, to classify observations acquired and to use the model of knowledge and the classification derived in order to assess situations, threats and refine the search for evidences.

The sources of information taken into account are those related to the intelligence domain, as IMINT, HUMINT, ELINT, COMINT and other non-conventional sources. The algorithms applied refer to not supervised and supervised classification for rule exploitation; adaptively built Hidden semi-Markov Model for situation and threat assessment in order to perform prediction; optimization techniques to refine the acquisition of information and maximize user awareness.

8407-30, Session 6

Multisource causal data mining

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Causal-View is a causal data-mining visualization tool being developed for the U.S. Army. Causal-View is built on an agent-enabled framework. The purpose behind using an agent structure is that much of the processing that Causal-view will do is in the background. When a user makes a request for information, e.g., information regarding a person of interest, Data Extraction Agents launch to gather information. This initial search is a raw, Monte Carlo type search designed to gather everything available that may have relevance to the individual, location, associations, and more. This data is then processed by Data-Mining Agents. The Data-Mining Agents are driven by user supplied feature parameters. For example, if the analyst is looking to see if the individual frequents a known haven for insurgents he may request information on his last known locations. On the other hand, if the analyst is trying to see if there is a pattern in the individual’s contacts, the mining agent can be instructed with the type and relevance of the information fields to look at. The same data is extracted from the database, but the Data Mining Agents customize the feature set in order to determine causal relationships that the user is interested in. At this point, a Hypothesis Generation and Data Reasoning Agents take over to form conditional hypotheses about the data and pare the data, respectively. The newly formed information is then published to the agent communication backbone of Causal-View to be displayed.

8407-31, Session 7

Evaluation of information relevance criteria within PEIRCE

P. Valin, Defence Research and Development Canada, Valcartier (Canada); G. Michaud, S. Paquet, Fujitsu Consulting Inc. (Canada)

Information relevance is an aspect of information fusion, where the relevancy of information is evaluated in a specific context. Multiple information relevance criteria were defined for application of information relevance in a military operational context. This theoretical work was based on an understanding of the military business and how relevancy of information is evaluated by humans during their work. In this paper, we present analysis results on the usefulness of information relevance criteria, applied in a Command and Control context. For this purpose, the Prototype for Extensible Information Relevance Criteria Experimentation (PEIRCE) was built and used with multiple variations of a Canadian Army scenario. A selected subset of the information relevance criteria was implemented into PEIRCE, with all required capabilities for performing performance evaluation, including Measures of Merit (MoM). Evaluation results describe the usefulness of criteria when used alone, but also their usefulness when multiple criteria are combined into a simple multi-criteria approach. Although some criteria have a higher usefulness than others, the combination of criteria usually provides a better measure of the usefulness of information.

8407-32, Session 7

Agent-based analysis of trustworthiness in wireless sensor networks

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Information assurance is a critical component of any organization's data network. Especially in the case of wireless sensor networks (WSNs), trustworthiness of the sensor data is an important metric for any application that requires situational awareness. In a WSN, information packets are typically not encrypted and the nodes themselves could be located in the open, leaving them susceptible to tampering and physical degradation. In order to develop a method to assess trustworthiness in WSNs, we have utilized statistical trustworthiness metrics and have implemented an agent-based simulation platform that can perform various trustworthiness measurement experiments for various WSN operating scenarios. Different trust metrics are used against multiple vulnerabilities to detect anomalous behavior, node failure as well as malicious attacks. The simulation platform simulates WSNs with various topologies, routing algorithms, battery and power consumption models, and various types of attacks and defense mechanism. Additionally, we adopt information entropy based techniques to detect anomalous behavior. Finally, detection techniques are fused to provide various metrics and various trustworthiness metrics are fused to provide aggregate trustworthiness for the purpose of situational awareness.

8407-33, Session 7

Practical considerations in Bayesian fusion of point sensors

C. P. Minor, Contractor (United States); K. R. Johnson, Naval Air Warfare Ctr. Weapons Div. (United States)

Sensor data fusion is and has been a topic of considerable research, but rigorous and quantitative understanding of the benefits of fusing specific types of sensor data remains elusive. Often, sensor fusion is performed on an ad hoc basis with the assumption that overall detection capabilities will improve, only to discover later, after expensive and time consuming laboratory and/or field testing that little advantage was gained.

The work presented here will discuss these issues with theoretical and practical considerations in the context of fusing chemical sensors with binary outputs. Results are given for the potential performance gains one could expect with such systems, as well as the practical difficulties involved in implementing an optimal Bayesian fusion strategy with realistic scenarios. Finally, a discussion of the biases that inaccurate statistical estimates introduce into the results and their consequences is presented.

8407-35, Poster Session

Adaptive IR and VIS image fusion

J. Rehacek, B. Stoklasa, Z. Hradil, Palack? Univ. Olomouc (Czech Republic)

The present technology makes it possible to acquire images of a given scene in different spectral bands, such as the visible and infrared bands. Having those separate views merged into a single composite image with higher information content is often desirable. Fusion methods in general should satisfy some requirements: Firstly, the fusion image has to preserve important information from both sources, secondly, the image should be easy to interpret by the observer. There exist many algorithms solving this problem varying in their capabilities to deal with different types of scenes. We implement several existing approaches and many different types of inputs. As it turns out, a universal algorithm cannot be found, that would deal with all types of lighting conditions in a satisfactory way. Therefore, an ideal system should react to the input and change its internal fusion procedures to produce the best possible outputs. In our contribution we present an alternative adaptive image fusion system based on neural network principle. Our system works with digitalized video sequences of visible and infrared band sensors, and is able to produce optimal results for a wide range of lighting conditions through an adaptive change of fusion algorithms. This change is driven by the change of the measured statistic of the input images. The best algorithm for the particular input is found by employing an objective measure of the fusion process quality. The system was trained by a set of typical inputs and its performance was tested in different experimental conditions.

8408-01, Session 1

Insider threat detection enabled by converting user applications into fractal fingerprints and autonomously detecting anomalies

H. M. Jaenisch, Licht Strahl Engineering, Inc. (United States) and The Johns Hopkins Univ. (United States); J. W. Handley, Licht Strahl Engineering, Inc. (United States)

We present a novel method for converting all applications on computers or networks into simple fractal function fingerprints. We then characterize these fingerprints using simple Heptor statistics and derive a Data Model change detector of the fingerprint statistics. This Change Detector is used as a template for nominal user file content and is observed for anomalous behavior according to the assigned work doctrine for applications and topics that are approved to be on the computer. Autonomous dynamic tracking of nominal and off nominal behaviors becomes possible with simple adaptive look-up-tables derived from behavior based Data Models. We show details of this method and encouraging results.

8408-02, Session 1

Cyber situational awareness and selective hardening

A. Dwivedi, D. J. Tebben, The Johns Hopkins Univ. Applied Physics Lab. (United States)

The advent of cyber threats has created a need for a new network planning, design, architecture, operations, control, management, and maintenance paradigms. Primary considerations include the ability to rapidly detect, isolate, and operate during deliberate simultaneous attacks against the nodes and links. Legacy network planning requirement of automatically protecting the network in an event of a single fault is rapidly being enhanced to include improved network resiliency to cyber attack vectors. Ability to design a resilient network requires the development of methods to define, and quantify the network resiliency to attacks, and to be able to develop new optimization strategies for maintaining operations in the midst of these newly emerging cyber threats. Ways to quantify resiliency and node criticality are presented in the current work, as well as a methodology of differential network hardening based on the node criticality profile of cyber networks.

8408-03, Session 1

Using inferred causal relationships for anomaly detection in multicast publish/ subscribe networks

L. A. Watkins, The Johns Hopkins Univ. Applied Physics Lab (United States)

In this paper, we focus on the problem of anomaly detection in multicast publish/subscribe (pub/sub) networks. This topology is useful for implementing robust and scalable message-based networks; however, the inherent loose coupling of pub/sub system components can obscure relationships and interactions between components that would typically provide the basis for network-based anomaly detection capability. A common approach to anomaly detection in general pub/sub networks is to use variable and hard to quantify features (e.g., message length, message structure, message content distributions), but this can result in a high number of false positives/negatives. We propose a new approach that uses more deterministic and quantifiable features (i.e., the causal relationships between the components of the system). Although these relationships are hidden within the pub/sub middle-ware and are not apparent at the network layer, one of the novel traits of our method is the ability to directly extract these relationships from the network traffic generated by the system. We then use these causal relationships as rules to distinguish normal operational network traffic from anomalous behavior in the network.

Our results show that across different instances of the system under test and in different operational scenarios, we can consistently and accurately detect the active components and many of their complex causal relationships. Further, these relationships have shown to be feasible rules whereby certain attacks (e.g., special classes of denial of service, hijacking, and others) have been identified with low rates of false positives/negatives.

8408-04, Session 1

From measurements to metrics: PCA-based indicators of cyber anomaly

F. Ahmed, T. Johnson, S. Tsui, The Johns Hopkins Univ. Applied Physics Lab. (United States)

We present the framework and results of the application of Principal Component Analysis (PCA) to automatically obtain meaningful metrics from cyber-sensed measurements, which can be used as quick and early indicators of malware.

The first step is to extract behavioral and structural measurements of malware using dynamic and static analysis techniques. Some examples of these measurements are: Length (in bytes) of the malware sample, Entropy distribution of the sample, Length of the behavioral analysis report, and Number of File Create/Delete/Write operations, Process Create/ Terminate, Registry Set/Delete etc., logged as part of the dynamic analysis.

The PCA provides us with principal components of the measurements, as linear combinations of original measurements. The final outcome of the process is the identification of a number of dominant metrics, which can be later used as fast and crude but effective discriminator of malware data in a generic cyber-sensing application.

Preliminary results with a limited set of malware samples and limited number of measurements show some promising results in classifying malware. It demonstrates some degree of separation of different types of malware clusters in the Principal Component domain. It also shows a different set of dominant attributes/measurements for different types of malware carriers (EXE, PDF, etc.). The resulting principal components, however, do not show high enough percentage of total variances that are typically explained by PCA. In this regard, the proposed work would utilize a larger set of malware ground truth data as well as applying a number of additional measurements. Finally, we also would like to analyze the stability of the dominant metrics as a function of intra-type changes in the ground truth data.

8408-05, Session 1

Anomaly detection for internet surveillance

H. Bouma, S. Raaijmakers, A. Halma, H. Wedemeijer, TNO Defence, Security and Safety (Netherlands)

Many threats to people or infrastructures in the real world can be related to the activity of persons on social media, blogs and forums. While the exact causal relationship is yet largely unknown, internet surveillance aims to prevent eventual attacks and assist in profiling suspects based on information from the cyber space. The information is gathered to improve situation awareness for the protection of citizens and critical infrastructures. However, the amount of data on the internet rapidly increases and it is time consuming for humans to monitor the continuous flow of tweets, posts and announcements on websites. In this paper, we present a novel method to automatically monitor trends and detect

behavior anomalies on Twitter or other social media. Specifically, we propose a profiling system based on non-negative matrix factorization and the correlation analysis of a number of variables, such as sentiment, retweets, post frequencies and topological properties of senders, medium and receiver. Correlation patterns between these variables are used for the profiling of network snapshots and individuals. In addition, we analyze pictures and combine the information from text and images to improve the overall system.

The system was tested on Twitter data. The results show that our system can successfully recognize abnormal changes in behavior, activity or emotion.

8408-06, Session 2

PeerShield: collaborative intrusion and vulnerability detection for wireless mobile networks

H. Cam, U.S. Army Research Lab. (United States)

Intrusion detection systems (IDS) in wireless mobile networks usually rely on that mobile nodes monitor transmission activities of each other and analyze packet contents to detect intrusions. But, it is shown experimentally that this type of IDS generate high false alarms, leading to poor intrusion detection performance and affecting adversely the already bandwidth-limited communication medium of wireless mobile networks. To mitigate the adverse impact of these monitoring-based IDS, this paper proposes a collaborative intrusion and vulnerability detection system, called PeerShield, where neighboring mobile nodes (i) collaboratively monitor, detect and gather intrusion and vulnerability data with primitives, (ii) aggregate the collected data by employing the proposed aggregation and risk scoring technique, (iii) verify the integrity of aggregated data using the proposed secure data aggregation technique as data is transmitted in multiple hops from mobile nodes to the base station of the network. In the proposed approach, when some nodes are suspected, their data traffic is treated differently, in accordance with their risk scoring. For instance, the amount of suspected nodes' data that is included in data aggregation depends on its risk scoring value. Those nodes whose data risk scoring values exceed a predefined threshold are cloned at other non-suspicious nodes. The proposed approach also creates dynamically an action graph for every mobile node to keep track of its data processing and communication operations. The deviations from the normal data processing and communication patterns in a mobile node are determined by checking sequences of operations in the action graph. The proposed mechanisms are evaluated with respect to their bandwidth efficiency and intrusion detection.

8408-07, Session 2

RISE: relational-integrity-sensitive-encoding for program intrusion detection

H. Cam, U.S. Army Research Lab. (United States)

Attacks aim at exploiting vulnerabilities of a program to gain control over its execution. By analyzing the program semantics, relational integrity, and execution paths, this paper presents a comprehensive approach to enhance the effectiveness of intrusion detection and prevention systems for malicious program traits. The main steps of our approach are: (i) extract main features and constraints of a program by focusing on its main entities such as functions, loops, instructions, variables, constants, and types; (ii) generate iteratively a corresponding new program in a concise form by aggregating its extracted features and constraints as well as generalizing uncritical parts of the initial given program, without violating program semantic properties, until the concise program is precise enough to verify the initial given program; (iii) first identify the main relational properties of every statement of the new concise program by considering those program statements that are to be executed before and after the statement execution, and then encode and associate these relational properties as the predicates or attributes of the statement; (iv) modeling the statements of the new program using constraint programming and constraint satisfaction problem such that each program statement is represented by a tuple that is composed of a number of variables corresponding to its main attributes and relational properties with other program statements; (v) classify the statements of the new program by associating colors with using our coloring technique, so that the instructions of those statements with different colors are restricted to access simultaneously certain memory locations; (vi) obtain an exploration of the program execution space for vulnerability discovery by applying a dynamic symbolic execution technique for generating new execution paths, computing symbolic constraints, and handling any existing encoding functions (e.g., decryption, decompression, hashing) on the input data; and finally (vii) insert small guards at vulnerable points of program by employing the above relational properties, predicates, coloring, and encoding. The evaluation of the proposed approach has shown promising results in intrusion detection.

8408-08, Session 2

Coalmine: a method of analyzing social networks for botnet command and control channels

J. S. White, J. L. Stacy, J. N. Matthews, Clarkson Univ. (United States)

Botnets are a growing concern to individuals, organizations, and governments. Many attacks against top level domains and related infrastructure come out of large, well managed botnets that can number in the millions. To control these malicious networks a bot master needs to provide the herd a constant stream of command messages. This paper presents a scalable and extensible framework for the detection of Botnet Command and Control (C2) channels that exist on social networking sites. Many difficulties exist in the collection and analysis of social networking data such as the sheer size of the of the datasets involved. The framework presented utilizes distributed processing tools and techniques to efficiently process large amounts of event based traffic. The method described within makes use of OSS tools such as Hadoop, Lucene, and HDFS to create a scalable distributed architecture for data-mining activities. This method differs from traditional threat detection by employing a model of proactive detection rather than reactive. The paper concludes with a presentation of the results from initial tests to detect botnet command and control channels on Twitter. These results present a real-world example of how this highly scalable and extensible system can detect various types of botnet C2 channels residing within social networking sites.

8408-09, Session 2

A method for the automated detection phishing websites through both site characteristics and image analysis

J. S. White, J. N. Matthews, J. L. Stacy, Clarkson Univ. (United States)

Phishing website analysis is largely still a manual process which takes the time of individuals to discover these sites and for others validate those claims. Additional time is incurred during URL distribution to blacklisting services. This paper presents a method which automates the laborious task of finding Phishing URLs and analysing them. This method relies on near real-time gathering of URLs posted on social media sites through use of a number of APIs. In addition the paper presents the issues incurred during the testing of this automated phishing site analysis and discussion the data sets used. A discussion of the relatively simplistic code used to glean characteristics for comparison of web-pages, and how they are weighted based on importance is made. Finally the paper concludes with an analysis of some of the phishing sites that were located using this method as the next steps in this research. This ongoing work at its core consists of 1.) automated data-mining of social media sites for URLs, 2.) parsing of URLs for characteristics that can be used in both direct comparison and page characteristic analysis, 3.) and automated site image capture and hashing for direct visual comparison.

8408-10, Session 2

Integrating cost effective security options into cloud computing

D. Kent, Cisco Systems, Inc. (United States)

When discussing cybersecurity, it is important to explore three distinct components that ensure the strongest protection against threats: trust, visibility and resilience. Trust builds the foundation for cybersecurity, determining the trustworthiness of those accessing the network. This network trust requires standard procedures that the organizations must perform in order to establish a trusted cybersecurity foundation to build upon. A network's visibility will enable the prevention and detection of unnecessary threats. Having a clear vision of the network will streamline the process of detecting a risk that is out of place because there is nothing that is hidden on the network. Resilience is the third component to implementing effective cybersecurity. Once a threat turns into a breach, it is important for the network to respond as quickly as possible and to learn from the breach in order to strengthen the network's cybersecurity to prevent any future incidents.

This session will discuss a variety of cost effective security options that are currently available in the technology and cybersecurity fields such as networks with built-in security features, including control points and endpoints. This session will explore the relative cost effectiveness and efficiency of existing network solutions and cloud computing and will also dive deeper into the three aforementioned considerations for maintaining an effective cybersecurity strategy.

8408-11, Session 3

A solution for parallel network architectures applied to network defense appliances and sensors

E. Naber, P. Velez, A. Johal, The Johns Hopkins Univ. Applied Physics Lab. (United States)

Network Managers have more network appliances available to them today than ever before, and an increasing number of them are aimed at securing the enterprise boundary. Over time, an enterprise accumulates multiple defensive network appliances (e.g., firewalls). Current network architectures require that these appliances be deployed in a serial fashion which creates a chain of network processing.

A serial architecture has numerous side effects. If a packet is dropped by an appliance, subsequent appliances will not process that packet. This introduces three significant limitations, (1) Stateful appliances placed later in the processing chain will maintain an internal "state" which will increasingly veer away from network reality; (2) The network manager cannot determine, or unit test, how each appliance would have treated each packet; (3) The appliance "votes" cannot be combined to achieve higher-level functionality.

To address these limitations, we have developed a novel, backwards-compatible parallel architecture that allows every appliance to process all network traffic and cast an implicit vote to drop or allow each packet. We then use a customizable algorithm to determine the outcome of each packet based on the individual decisions made by each appliance. This "crowd-sourcing" approach allows the network designer to take full advantage of each appliance, fully understand how each appliance is behaving, and achieve behavior not possible with a single appliance. We have implemented this architecture and successfully demonstrated the collaboration of hardware and software based defense appliances. Initial tests have shown promising results for maintaining parallel traffic processing at near line speed.

8408-12, Session 3

Data fusion in cyber security: first order entity extraction from common cyber data

N. A. Giacobe, The Pennsylvania State Univ. (United States)

The Joint Directors of Labs Data Fusion Process Model (JDL Model) provides a framework for how to handle sensor data to develop higher levels of inference in a complex environment. Beginning from Tim Bass's 2000 call to leverage data fusion techniques in intrusion detection, there have been a number of advances in the use of data fusion algorithms in this sub-domain of cyber security. While it is tempting to jump directly to situation-level or threat-level refinement (levels 2 and 3) for more exciting inferences, a proper fusion process starts with lower levels of fusion in order to provide a basis for the higher fusion levels. The process begins with first order entity extraction, or the identification of important entities represented in the sensor data stream. Current cyber security operational tools and their associated data are explored for potential exploitation, identifying the first order entities that exist in the data and the properties of these entities that are described by the data. Cyber events that are represented in the data stream are added to the first order entities as their properties. This work explores typical cyber security data and the inferences that can be made at the lower fusion levels (0 and 1) with simple metrics. Depending on the types of events that are expected by the analyst, these relatively simple metrics can provide insight on their own, or could be used in fusion algorithms as a basis for higher levels of inference.

8408-13, Session 3

The distributed nature of cyber situation awareness

M. J. Tyworth, N. A. Giacobe, V. Mancuso, The Pennsylvania State Univ. (United States)

In this paper we present findings from our ongoing empirical investigation of how cybersecurity analysts develop situation awareness - or the 'big picture' - of cyberspace. Drawing from over twenty interviews of cybersecurity analysts and professionals working in the military, government, industrial and educational domains, we find that cyber situation awareness (CSA) is distributed across operating in and for different functional domains. These domains include intrusion detection, operations, strategic monitoring of the threat landscape, and policy. Development of boundary spanning technological artifacts capable of fusing multi-domain information is critical to facilitating robust CSA.

Situation awareness is a cognitive process of detecting salient information in the environment, comprehending the meaning of those cues, and correctly projecting some future state based on that comprehension. However, detecting the salient cues in cyberspace in which the volume of information to process is on an unprecedented scale and there are no physical boundaries to the environment poses distinctly unique challenges to the human operator. Indeed our data suggests that CSA is distributed precisely because no one individual can see the entire picture due to its size.

What are needed are technological systems that function as boundary objects between the operators working in different functional domains. These boundary object systems need to be at once 'rigid' enough to have a shared understanding across domains and 'plastic' enough to be individual configurable and interpretable for domain-specific awareness needs. We have begun exploring a promising approach to this problem that incorporates cyber security data with geospatial representation.

8408-14, Session 3

Operational advantages of using cyber electronic warfare in the battlefield

N. Yasar, F. M. Yasar, Turkish Air War College (Turkey)

Today, while cyberspace emerges as a new battlefield, conventional electronic warfare (EW) methods and applications are likely to change.

At this context, Cyber Electronic Warfare (CEW) concept can be defined as a novel warfare concept which includes merging cyberspace capabilities with well-known EW methods.

In this study the feasibility of integrating cyber warfare logic into EW measures is researched. A comparison of CEW concept and conventional EW applications is presented. The operational advantages of CEW is assessed by means of its effects on adversary air defence systems, communication networks and information systems. Outstanding technological and operational difficulties are pointed out.

It is concluded that, utilization of CEW concept is feasible at the battlefield and it may yield important operational benefits.

8408-16, Session 4

Analysis of web-related threats in ten years of logs from a scientific portal

R. D. Coelho dos Santos, The Johns Hopkins Univ. (United States) and Instituto Nacional de Pesquisas Espaciais (Brazil); A. R. A. Grégio, Ctr. de Tecnologia da Informação Renato Archer (Brazil); J. Raddick, V. Vattki, A. Szalay, The Johns Hopkins Univ. (United States)

SkyServer is an Internet portal to the Sloan Digital Sky Survey (SDSS) Catalog Archive Server, which contains data from a survey that maps one-quarter of the entire sky, containing detailed information on hundreds of millions of celestial objects. SkyServer provides free access to SDSS data in different ways, supporting astronomy research, public outreach and education, and allowing access through web forms, services and SQL queries.

Logs of access to SkyServer and related tools have been collected continuously for more than ten years, and contains more than 930 million web hits, 140 million web services accesses and 170 million SQL submitted queries. Presently, these logs are being analyzed in order to characterize SkyServer users (human and bots) and which tools and services they use most.

As expected, these logs contain several entries that indicate some intrusion or compromise attempts on the servers. Since SkyServer is a scientific and education portal, the analysis of the threats it was exposed to may yield interesting information on general and directed attack attempts on this type of portal.

This paper describes which security-related events were detected in ten years of logs on the SkyServer portal, comparing attack patterns found on the logs with threats expected to be found on the web in different years, using the Open Web Application Security Project (OWASP) list of Top Ten risks associated with Web applications for this ten-year time frame. Moreover, we present an analysis on the evolution of the threats over those ten years.

8408-17, Session 4

Improved stepping stone detection through active watermarking

J. I. Gilbert, D. J. Robinson, Air Force Institute of Technology (United States)

Network intrusions have become increasingly sophisticated at masking malicious actions. A tactic of particular interest is compromising vulnerable hosts and using them as relay points, or stepping stones, to gain a foothold into the network. Indeed, leveraging a trusted host enables an attacker to obtain seemingly authorized access to more secure areas of the network, while hiding their actions from detection. Research for identifying stepping stones has focused primarily on traffic analysis of network streams. Passive analysis was first introduced to identify traffic flows with common characteristics, including packet timing, counts and sizes. However, recent active watermarking analysis techniques have demonstrated lower error rates, while computationally less expensive.

This research introduces an enhanced method of applying active watermarking techniques for analysis of network streams. Current watermarking techniques statically modify packet delays to encode information in the packet stream. We introduce an algorithm that dynamically alters packet delays based on packet statistics, providing the ability to optimize parameter selection for each individual network stream. Simulation and network analysis demonstrate increased algorithm efficiency and a higher rate of stepping stone detection.

8408-18, Session 4

Distributed pattern detection in cyber networks.

R. C. Paffenroth, P. C. Du Toit, Numerica Corp. (United States); L. L. Scharf, A. P. Jayasumana, V. Banadara, Colorado State Univ. (United States)

We describe the detection and classification of weak, distributed patterns in sensor networks. Of course, before one can begin development of a pattern detection algorithm, one must first define the term ``pattern” which by nature is a broad and inclusive term. One of the key successes of our work is a precise definition of pattern that has already proven effective in detecting anomalies in real world data. While designing detection algorithms for all classes of patterns in all types of networks sounds appealing, this approach would almost certainly require heuristic methods and only cursory statements of performance. Rather, we have specifically studied the problem of intrusion detection in computer networks in which a pattern is an abnormal or unexpected spatio-temporal dependence in the data collected across the nodes. We do not attempt to match an a priori template, but instead have developed algorithms that allow the pattern to reveal itself in the data by way of dependence or independence of observed time series. Although the problem is challenging, recent advances in L1 techniques for robust matrix completion, compressed sensing, and correlation detection provide promising opportunities for progress. Our key contribution to this body of work has been the development of methods that make a careful accounting of uncertainty in the measurements on which the inferences are based. The efficacy of our methods will be demonstrated on real world data, including measured data from the Abilene Internet 2 network.

8408-19, Session 5

Novel sensing paradigm based on dynamic logic theory in collaborative tracking systems

L. I. Perlovsky, Air Force Research Lab. (United States)

A novel sensing paradigm based on Dynamic Logic Theory is described in multi-sensor heterogeneous processing environment for combining range and Doppler data from multiple platforms to perform multi-target detection and tracking. Increasing the number of sensors can cause data association by conventional means to become impractical due to combinatorial complexity, i.e., an exponential increase in the number of mappings between signatures and target models. When the azimuthal resolution is coarse, this problem will be exacerbated by the resulting overlap between signatures from multiple targets and clutter. In the presented approach, the data association is performed probabilistically, using a variation of expectation-maximization based on Dynamic Logic Theory. Combinatorial complexity is avoided by performing an efficient optimization in the space of all target tracks and mappings between tracks and data. The results based on simulated data demonstrate that accurate tracks can be estimated by exploiting spatial diversity in the sensor locations.

8408-20, Session 5

Improved near-Earth objects detection using dynamic logic

I. V. Ternovskiy, T. G. Allen, Air Force Research Lab. (United States)

Current efforts aimed at detecting and identifying Near Earth Objects (NEOs) that pose potential risks to Earth use moderately sized telescopes combined with image processing algorithms to detect the motion of these objects. The search strategies of such systems involve multiple revisits at given intervals between observations to the same area of the sky so that objects that appear to move between the observations can be identified against the static star field. Although the research in this paper uses asteroids for the unsupervised detection, the ultimate extension of this study is detecting unknown manmade objects posing a threat to digital/network infrastructure.

Dynamic Logic algorithm has made significant improvements in detection, tracking, fusion of ground radar images. The research in this paper will examine Dynamic Logic's ability to detect NEOs without any human-in-the-loop intervention. Many asteroid orbits are well defined, so they will serve well as excellent test cases for the algorithm validation.

8408-21, Session 5

Automatic decision support in large-scale heterogeneous sensor networks

R. Kozma, The Univ. of Memphis (United States)

There is a need to model complex interactions in large-scale sensor networks in order to provide efficient tools of decision support in rapidly changing, dynamic real life scenarios. In practical terms, decisions must be made rapidly based on the combination of often thousands, or hundreds of thousands sensory channels, presenting formidable challenges to efficient decision support. Hence, we experience the paradoxical situation of being able to sense (in physical space) various events without having the capability of processing them efficiently to support robust decisions in cyber space.

Large-scale networks often have certain common key features: They are scale-free, i.e., the distribution of the degrees of their nodes follows a power law. They frequently exhibit the small-world phenomenon, where the diameter of the network, i.e., the maximum number of steps needed to get from one node to another, is often small. These networks can grow and evolve through time, e.g., the evolution of new links with steadily growing and branching connections between sites. The growth often assumed to be some kind of preferential attachment, i.e., new vertices are more likely to be joined to existing vertices which already have a lot of connections. Scale-free networks with their evolving hub structure are widespread in cyber domain, and have the important advantage of being resistant to random decay or malicious attacks. They have, however, their Achilles' heel; namely, well-targeted malicious attacks aimed at their major hub nodes can paralyze the operation of the overall network. Nature invented a unique resilient network in our brain, which is not scale free by its structure, but exhibits robust behavior in response to a range of random and targeted attacks. It is a combination of regular short-range cellular structures and a small number of medium- and long-range connections. This network structure has been studied in neuropercolation models and serves as an example of networks with the desired resilience.

A critical property of the studied networks is the frequent onset of phase transitions, when large clusters of highly structured behaviors emerge intermittently from the mostly unstructured background activity. We employ a very deep and surprising mathematical finding which states that every very large graph (structural or functional) can be partitioned into a few regular components of about the same size, connected by a small number of random links. These mathematical advances are employed to develop resilient networks. The studied testbed includes wireless pervasive RF transceivers combined with various sensor modalities, including optical image,acoustic, infrared sensors. We embed the physical sensor network into cyber domain to achieve robust and resilient operation in adversary conditions.

8408-22, Session 5

Multi-agent system for target-adaptive radar tracking

A. C. O'Connor, Air Force Research Lab. (United States)

Sensor systems such as distributed sensor networks and radar systems are potentially agile - they have parameters that can be adjusted in real-time to improve the quality of data obtained for state-estimation and decision-making. The integration of such sensors with cyber systems involving many users or agents permits greater flexibility in choosing measurement actions.

This paper considers the problem of selecting radar waveforms to minimize uncertainty about the state of a tracked target. Past work gave a tractable method for optimizing the choice of measurements when an accurate dynamical model is available. However, prior knowledge about a system is often not precise, for example, if the target under observation is an adversary.

A multiple agent system is proposed to solve the problem in the case of uncertain target dynamics. Each agent has a different target model and the agents compete to explain past data and select the parameters of future measurements. Collaboration or competition between these agents determines which obtains access to the limited physical sensing resources. This interaction produces a self-aware sensor that adapts to changing information requirements.

8408-23, Session 5

Application of dynamic logic algorithm to analyze AFRL gotcha data

F. Lin, Air Force Research Lab. (United States)

In this paper, we apply Dynamic Logic Algorithm (DLA) directly to analyze AFRL Gotcha SAR raw data, which has not been done in the existing literature. Traditionally, target detection, tracking, or classification was accomplished by using SAR images or range-Doppler profiles, which can be easily perceivable to scientists' comprehension. However, to generate SAR images or range-Doppler profiles, it requires extra computational complexity. Unlike those traditional signal processing techniques, the AFRL in-house DLA can detect, track, and classify ground moving targets simultaneously. We have demonstrated that application of DLA to SAR

raw data not only reduces computational complexity but also extracts specific features for moving vehicles from chirp frequency samples and pulses in SAR raw data.

8408-24, Session 6

Toward automatic scene understanding using hierarchical associative approach

I. V. Ternovskiy, Air Force Research Lab. (United States)

A conflict exists between the amount of video information in existing multi-sensor surveillance systems and real-time sensors output. An automatic real-time scene understanding system that can recognize objects in multiple sensor video streams, infer the topology and relationship of the identified objects, and then perform a real-time tagging and description of the scene could significantly reduce the human involvements and network traffic in real time surveillance and reconnaissance systems. We propose an approach based on invariant, physics based object extraction and recognition, and scene understanding based on associative uncertainty modeling. In other words our algorithms will identify objects, and their topology, orientation, shape, proximity, similarity, and size and provide relationships among them. The proposed approach will enable to develop an autonomous tagging and scene understanding system that can integrate multiple video streams, in conjunction with other available imagery, to discriminate objects against natural backgrounds, even if the image is partially occluded, and from them generate real-time tagging and a plain description of the scene.

8408-25, Session 6

Human-computer symbiosis in cyberspace environments

E. Levin, J. F. Carter, A. V. Sergeyev, Michigan Technological Univ. (United States)

The main goal of a cyberspace environment is to support decision makers with relevant information on time for operational use. One of the most challenging issues associated with efficient decision making support in cyberspace environments deployed for communication networks, transportation, finances, and standard utilities of a nation's critical infrastructure is associated with timely processing and analysis of remotely sensed geospatial data. This data includes terrestrial, aerial/UAV, satellite and other multi-sensor data obtained in electro-optical and other imaging domains. Despite advances in automated geospatial image processing, the "human in the loop" is still necessary because current applications depend upon complex algorithms and adequate classification rules can only be provided by skilled geospatial professionals. One innovative and promising solution is associated with applying human-centric geospatial technologies as a way to utilize human-computer symbiosis for accelerated control of the vast amounts of geospatial data processing in cyberspace systems. The ultimate goal of cognitive geospatial science and technology research and development is establishing an interactive geospatial environment optimizing decision support workflow, making it more efficient, and accelerating productivity by producing automatic reactions to an analyst's attention, emotions, and minds. Thus signals extracted from humans become an element of a cyberspace system. This paper describes an innovative approach and research experiments on integrating wireless wearable electroencephalography (EEG) device within geospatial technology workflow. Preliminary results indicates opportunities of design geospatial systems controlled by "power of the human mind".

8408-26, Session 6

WFS alignment and calibration techniques for the laser communication system

A. V. Sergeyev, E. Levin, M. C. Roggemann, Michigan Technological Univ. (United States)

Laser communication systems operate in the presence strong atmospheric turbulence, affecting communication platform by broadening of the laser footprint, random jitter of the laser beam, and high spatial frequency intensity fluctuations referred to as scintillation. The prediction of the effects induced by the atmospheric turbulence is a crucial task for the reliable data transmission. Equipping the lasercom platform with adaptive optics system capable of probing the atmospheric turbulence and generating the data on wave front errors in real time improves performance and extends the range of optical communications systems. Most adaptive optics systems implement wavefront sensors to measure the errors induced by the atmospheric turbulence. Real time analysis of the data received from the wavefront sensor is used for outgoing laser beam compensation significantly busting the lasercom performance. To obtain reliable wavefront sensor data, the wavefront sensor needs to be accurately aligned and calibrated. To model the performance of a laser communication system operating in the real world we have developed an outdoor 3.2 km, partially over water, turbulence measurement and monitoring communication link. The developed techniques of wavefront sensor alignment and calibration led to the successful data collection and analysis are discussed in this paper.

8408-27, Session 6

Bio-inspired visual and olfactory receptor system for elusive target detection

T. A. Duong, Adaptive Computation LLC (United States)

In this paper, we present an integration technique for bio-inspired visual and olfactory receptor systems to search for elusive targets in various environments where the targets cannot be seen obviously by either sensory data. Bio-inspired visual system is based on a modeling of extended visual pathway which consists of saccadic eye movements and visual pathway (vertebrate retina, lateral geniculate nucleus and visual cortex) to enable powerful target detections of noisy, partial, and incomplete visual data. Olfactory receptor algorithm, namely spatial invariant independent component analysis, that was developed based on data of olfactory receptors -- electronic nose (e-nose) of Caltech, is adopted to enable the odorant target detection in an unknown environment. The integration of two systems is a vital approach and establishes a corner stone for effective and low cost development of miniaturized UAVs or fly robots for future DOD and NASA missions.

8408-28, Session 7

Scalable framework for sensor trustworthiness assessment

C. Wu, D. Phillips, S. Marotta, G. Fry, Charles River Analytics, Inc. (United States); L. Girod, Massachusetts Institute of Technology (United States)

To address the challenge of processing data from potentially faulty sensors, we developed a framework to analyze sensor-related data and assess the trustworthiness of sensors within a sensor network. The framework allows a sensor network administrator to track sensor trustworthiness over time. The framework is designed to support multiple data classifiers that can run in parallel or series. These classifiers can be distributed across the sensor network for greater flexibility and scalability. The framework is also designed to be hierarchical, so the output of one classifier can feed another, which would then classify data at a higher level of abstraction. A trustworthiness assessor processes the output

of the classifiers to infer the trustworthiness of each sensor over time. Finally, a user interface component allows the network administrator to monitor the sensor trustworthiness and other data.

For validation, we implemented a multi-tier trustworthiness assessment system with two types of anomaly-based classifiers running in parallel and series across multiple sensor nodes. The classifiers included features to assist the administrator in tuning the parameters based on characteristics of the training data. We implemented a trustworthiness assessor, and we also integrated an existing network visualization tool to demonstrate the ease of integrating COTS and GOTS components into the framework. We performed several experiments with data collected from experimental sensor networks and network simulations. These experiments validated our general framework as well as the classifier, assessor, and interface components across multiple domains and sensor modalities.

8408-29, Session 7

Trust and microblogging: a proposed framework for assessing trust in Twitter

K. A. Moore, The Pennsylvania State University (United States)

Twitter is regularly used to communicate information in weak social networks during crisis events. However, the desire to use Twitter feed towards decision making activities by crisis responders and national security analysts is constrained by the lack the of trust in the information provided. Whereas intelligence analysts are trained in deconstructing and analyzing data, crisis responders are not. Therefore, developing a mechanism for assessing trust in microblogged data in a timely and efficient way is of great interest and use to both communities.

Of the numerous proposed methods for assessing trust in human message data, none have fully grounded themselves in the examination of trust on an interpersonal level, nor have they extended this examination to online manifestation in a computer mediated environment, particularly social media. This work presents a new theoretical model for assessment that incorporates previously suggested systems in the framework of Analysis of Competing Hypotheses, a well-established analytical methodology used in the national security community. By grounding research firmly in the social sciences and examining the current work in the area of Crisis Informatics, the implications for this research are twofold. First, is the introduction of basic analytic techniques for assessment to the crisis response community. Second is the introduction of a model by which to base future automation of microblog data for both crisis responders and the national security community.

8408-30, Session 7

Tracking fine-grained topics in microblogs

N. F. Sandell, M. R. Luettgen, Systems and Technology Research, Inc. (United States); G. Cybenko, Dartmouth College (United States)

Modern microblogging services provide a wealth of information about the state of the world. In recent years there has been a large volume of research directed at extracting information from microblogging services for both engineering and scientific purposes. For example, engineering applications have included detecting world events, filtering uninteresting content from personal feeds, and directing attention to new and upcoming viral phenomena. Scientific investigations include modeling social structure, information diffusion across the network, identifying key individuals in the network and identifying the spread of dubious information. A common, critical component in much of this research is identifying units of information (termed “memes”) as they propagate through the microblog space. Heretofore, most research has avoided answering the general solution to this problem in favor of simple solutions that can only detect a small subset of these memes, and extract only a subset of messages relevant to the detected memes. A more general solution faces a number of technical challenges relating to the massive volume of messages. First, algorithms must be sufficiently scalable to process the large number of messages in short order. Second, the skew in the number of messages relating to a meme against those unrelated is enormous - requiring false association probabilities to be extremely small. In this paper, we introduce a methodology of tracking messages relating to a meme that addresses these key challenges, and present empirical results from real microblog data.

8408-31, Session 7

Towards a trustworthy distributed architecture for complex sensing networks

H. C. Schubert, Real-Time Innovations (United States); J. Luke, Air Force Research Lab. (United States)

Fast, efficient distributed computing enables much more capable sensing systems for defense and commercial applications. However, distributed systems face distributed threats. These threats can be countered with a distributed trustworthiness architecture that measures and enforces trust across a network. Currently, there are no designs for distributed trust architectures suitable for high performance complex systems.

We present such an architecture where two different components of trustworthiness are proposed: an a priori component, which classifies a node before it joins the network, and a dynamic component, which is updated depending on the node’s behavior while communicating. Our approach leverages relevant attributes for defining the trustworthiness index, i.e., properties that can be attached to a software component, and properties that change with behavioral changes in operation. Our framework relies on structured assurance case models to characterize both the a priori and dynamic scenarios, and uses a weight-based method to compute the trustworthiness index.

In order to facilitate the computation and enforcement of trustworthiness index, a distributed sensing network has to integrate a new type of component called trust agents. We define the trust agents in terms of capabilities that support the trustworthiness measurements. Moreover, we present a prototype of a trust agent that computes both the a priori and dynamic trustworthiness indexes. The trust agent allows communication between applications with acceptable trustworthiness levels, while monitoring relevant attributes that characterize nodes’ behavior.

8408-32, Session 7

Blind extraction and security analysis of multimedia spread spectrum hidden watermarks

J. A. Marsh, SUNY Institute of Technology (United States) and Assured Information Security, Inc. (United States); G. F. Wohlrab, Air Force Research Lab. (United States)

We consider the security of spread-spectrum hidden watermarks in compressed images, and report on results of algorithm development and testing. Our algorithm is an extension of the Iterative Generalized Least Squares (IGLS) technique for signature extraction developed by Gkizeli et. al. (Proc. IEEE Intern. Conf. Image Proc. (ICIP), 2005), and performs fully blind extraction through repeated IGLS trials in which k-means clustering is used to identify successful signature extraction. In this algorithm Hamming distance between extracted binary signatures is used as a metric when seeking clusters. We describe our algorithm, referred to as the Blind Clustering IGLS (BC-IGLS), in detail and demonstrate its effectiveness in a suite of experiments using DCT coefficients of JPG images as host data. Our results include detection theory metrics characterizing BC-IGLS behavior as a function of embedding amplitude, signature length, and number of hidden bits, showing excellent performance. Waterfall plots of BER vs. embedding amplitude characterize the BC-IGLS algorithm performance for a variety of host images, and we demonstrate the existence of a threshold embedding amplitude that delineates the secure region for hidden watermarking. This threshold is found to be image-dependent. At embedding amplitudes just below this threshold, secure embedding is achieved, yet BER is low enough to assure dependable data extraction using the known hiding signature.

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8408-33, Session 7

Fractals, malware, and data models

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Analysis of malware and non-malware typically results in the finding that there is no linear decision boundary between the two. Yet the potential of finding a classifier that offers a reliable distinction between malware and non-malware holds significant value for further understanding and protection against malware. We examine the hypothesis that the decision boundary between malware and non-malware is fractal. We introduce a novel encoding method derived from text mining for converting disassembled programs first into opstrings and then filter these into a reduced opcode alphabet. These opcodes are enumerated and encoded into real floating point number format and used for characterizing frequency of occurrence and distribution properties of malware functions to compare with non-malware functions. We use the concept of invariant moments to characterize the highly non-Gaussian structure of the opcode distributions. We then derive Data Model based classifiers from identified features and interpolate and extrapolate the parameter sample space for the derived models to examine the nature of the parameter space classification boundary between families of malware and the general non-malware category. Preliminary results strongly support the fractal boundary hypothesis and a summary of the method and results are presented here.